ATLANTIC WIND TEST SITE

WIND/DIESEL RESEARCH AND DEVELOPMENT FACILITY
AT THE ATLANTIC WIND TEST SITE
for
SOLAR ENERGY DEVELOPMENT PROGRAM

Prepared for:

SOLAR ENERGY DEVELOPMENT PROGRAM
ENERGY, MINES AND RESOURCES CANADA
OTTAWA, CANADA
DSS CONTRACT FILE NO: 545Z-23216-6-6155
1987 08 06

Prepared by:

THE INSTITUTE OF MAN AND RESOURCES
THE ATLANTIC WIND TEST SITE
49 POWNAL STREET
CHARLOTTETOWN, PEI
C1A 3W2
902-892-0361
902-882-2746

T4-W4-
86-6155

INSTITUTE OF MAN AND RESOURCES

WIND/DIESEL RESEARCH AND DEVELOPMENT FACILITY AT THE ATLANTIC WIND TEST SITE for SOLAR ENERGY DEVELOPMENT PROGRAM

PREPARED FOR:

SOLAR ENERGY DEVELOPMENT PROGRAM
ENERGY, MINES AND RESOURCES CANADA
OTTAWA, CANADA
DSS Contract File No: 545Z-23216-6-6155
1987 08 06

PREPARED BY:

THE INSTITUTE OF MAN AND RESOURCES
THE ATLANTIC WIND TEST SITE
49 POWNAL STREET
CHARLOTTETOWN, PEI
C1A 3W2
902-892-0362
902-882-2746

SCIENTIFIC AUTHORITY

MONIQUE CARPENTIER
TECHNOLOGY COORDINATOR-WIND ENERGY
SOLAR ENERGY DEVELOPMENT PROGRAM
ENERGY, MINES AND RESOURCES
4600 CONNOR STREET
4th FLOOR
OTTAWA, ON
K1A 0E4

DISCLAIMER

This report is distributed for informational purposes only and does not necessarily reflect the views of the Government of Canada nor constitute an endorsement of any commercial product or person. Neither Canada nor its ministers, officers, employees or agents make any warranty in respect of this report or assumes any liability arising out of this report.

PREFACE

This report concludes a contract between the Government of Canada and the Atlantic Wind Test Site (AWTS) to relocate an existing wind/diesel development system from Sudbury, Ontario, to the AWTS in Prince Edward Island.

The reports describes the system as installed and outlines the modifications to the original system which has resulted in a much more useful and versatile development system.

This work will provide the foundation for continuing wind/diesel technology development in Canada.

This report will be of interest to anyone interested in wind energy and wind/diesel technology particularly as related to the controls, data acquisition, and field installation aspect of wind/diesel systems.

EXECUTIVE SUMMARY

Wind/diesel technology has been recognized in Canada as an application of wind energy with immediate economic potential. Work had been carried out by the government of Canada from 1978 to 1984 in a number of projects culminating with an autonomous wind/diesel development system installed at Sudbury, Ontario. The project described in this report included the dismantling of the Sudbury equipment and the relocation of that equipment to the Atlantic Wind Test Site (AWTS) in Prince Edward Island where it was reassembled with the intent to provide a development system and to establish a center of expertise in wind/diesel technology in Canada.

The report details the work performed and describes the final installation. The equipment, as presently installed, will provide a facility for development of wind/diesel technology in the areas of autonomous wind operation, short term energy storage, and load management.

The report also describes the selection and installation of control systems capable of providing the necessary control functions for meeting current and future requirements.

The report concludes that with the completion of some minor outstanding technical issues, the wind/diesel test bed at the AWTS is ready for the initiation of wind/diesel development programs to resolve outstanding technical issues facing the technology.

TABLE OF CONTENTS

I.	Disclaimer	i
II.	Preface	ii
III.	Executive Summary	iii
IV.	Introduction	1
V.	Objective	1
VI.	Installation	2
VII.	Discussion of Installation Results	14
VIII.	Conclusion	16
IX.	Recommendations	17
X.	Appendix A AWTS Data Acquisition System	A1
XI.	Appendix B Wind/Diesel Control System Investigation	B1
XII.	Appendix C AWTS Wind/Diesel Connection Diagram	C1
XIII.	Appendix D AWTS Wind/Diesel System Wind Turbine Control System	D1

WIND/DIESEL RESEARCH AND DEVELOPMENT FACILITY AT THE ATLANTIC WIND TEST SITE

INTRODUCTION

Canada has been involved in wind diesel research and development since 1978 when the National Research Council, Energy Mines & Resources, and Ontario Ministry of Energy in conjunction with DAF Indal (now Indal Technologies) installed and tested a small wind/diesel experimental system on Toronto Island. They later installed a 35 KW DAF Vertical Axis Wind Turbine, two diesel generators and simulated community loads near Sudbury, Ontario. During the following several years tests were carried out to determine the effect of wind diesel operations on fuel economy and operational characteristics on a simulated small grid. Tests were carried out using both mechanical and electrical coupling of the wind turbine to the diesel generators. Penetration levels ranging from zero to autonomous wind operation were evaluated. The results of these tests have been extensively reported by Indal Technologies (Ref 1, 2 & 3).

The tests carried out at Sudbury gave some very encouraging results for wind diesel application and it was intended to continue development work at that site. Changes in federal government energy spending, however, resulted in suspension of the test programs and put further wind/diesel development work in Canada on hold.

In 1985 The Institute of Man and Resources proposed to relocate equipment sitting idle at Sudbury to the Atlantic Wind Test Site to enable continued development of the technology. Relocation to an existing site with full time staff will make support and operation of the system much less expensive and enable researchers from all of Canada to access the equipment for development work without spending an inordinate amount of time becoming familiarized with routine operating procedures. As a result the efficiency of the test bed as a development tool will increase.

OBJECTIVE

The objective of this work was to acquire the Sudbury wind/diesel system consisting of a 17 M Indal VAWT (35kw), two 50 kw diesel generators, dump loads and related ancillary equipment, and relocate it to the Atlantic Wind Test Site (AWTS) at North Cape, Prince Edward Island. The equipment is intended to provide a wind/diesel development system which Canadian researchers may use to investigate and solve the remaining technical problems facing

the technology. The new installation was to provide a more flexible facility that could effectively accommodate future study on such subjects as; penetration levels, short term storage, and autonomous wind turbine operation using either vertical or horizontal axis wind turbines. Energy storage investigations using inertial or battery storage systems, load management methods and potentially actual residential grid interconnection were also proposed as possible elements of future work.

INSTALLATION

The tasks described below were performed and have been concluded. These tasks formed the work statement of the proposal to perform this work.

Task 1 Study drawings and specifications of all equipment.

This task involved the preliminary work necessary to plan the project design. Original intent for AWTS engineers to visit the site to conclude arrangements for the move were cancelled due to time restrictions.

Task 2 Design and layout foundation.

Foundation and anchor requirements as specified by manufacturer were studied and an investigation made to determine the feasibility of using an existing foundation and anchors installed at AWTS. The design study concluded that with some modifications the existing foundations were capable of providing adequate support and the required modifications were initiated.

Task 3 Design electrical interface.

The electrical interface for the wind/diesel installation at the AWTS required substantial modification from the original Sudbury configuration. The system installed at Sudbury was designed to simulate a remote community and as such had no utility interconnection. It was decided that for the AWTS project this would restrict the versatility of the test facility. Thus, the system was interfaced with the utility to allow the technology to be developed in a modular fashion. This interface (Fig 1) permits the wind turbine to be operated on either the utility grid or on the diesel grid. On the diesel grid it may be operated either in parallel with the diesel or in an autonomous mode.

The wind turbine can be coupled to the diesel grid with an electrical connection only. The mechanical connection tested in Indal Technologies "Sudbury I" project (Ref 2) is no longer possible. Although mechanical coupling has certain interesting possibilities it was felt that electrical coupling for such a system has many more practical applications. Instead of using the original system concept of connecting the wind turbine to a synchronous generator for autonomous operation, an induction generator was installed. To allow autonomous operation, reactive power will be supplied by #1 generator which can be decoupled from the #1 diesel by a cam clutch and operated as a synchronous condenser. Using this method the #1 diesel can be shut down allowing the #1 generator to continue to rotate, supplying reactive power to the diesel grid during automous wind turbine operation. The system controller will than regulate system performance by sensing system frequency and placing loads on the system to maintain stable supply within acceptable frequency variations.

A further modification to the electrical interface was to enable connection of the starter motor to the utility grid. While this compromises the true simulation of an autonomous system, it was felt that a number of technical problems related to wind/diesel operation using VAWTS exists and that the resolution of these problems is easiest when addressed one at a time. The problems of energy requirements when starting a VAWT on a small grid is recognized, and work is needed on this subject.

Task 4 Design instrumentation and data acquisition systems.

The instrumentation on the wind/diesel systems at Sudbury was adequate to perform cumulative measurements on wind speed, power, performance, and fuel consumption under varying load and wind conditions. Most parameters were measured on an instantaneous basis or from regular integrator readings. At AWTS, these measurements as well as several additional points required to enable 24 hour/day assessment of the system will be possible. The data acquisition system that has been installed for this performance monitoring is a Campbell Scientific CR21 datalogger. This unit connected to the AWTS base data acquisition system by an RF telemetry link. Appendix A describes the AWTS data acquisition system.

Task 5 Construct foundations.

The foundations (Figures 2 & 3) were constructed as shown in the wind/diesel plant arrangement (Figure 5). The module base was constructed by addition of a reinforced concrete cup to an existing foundation for a 11M X 17M Indal VAWT.

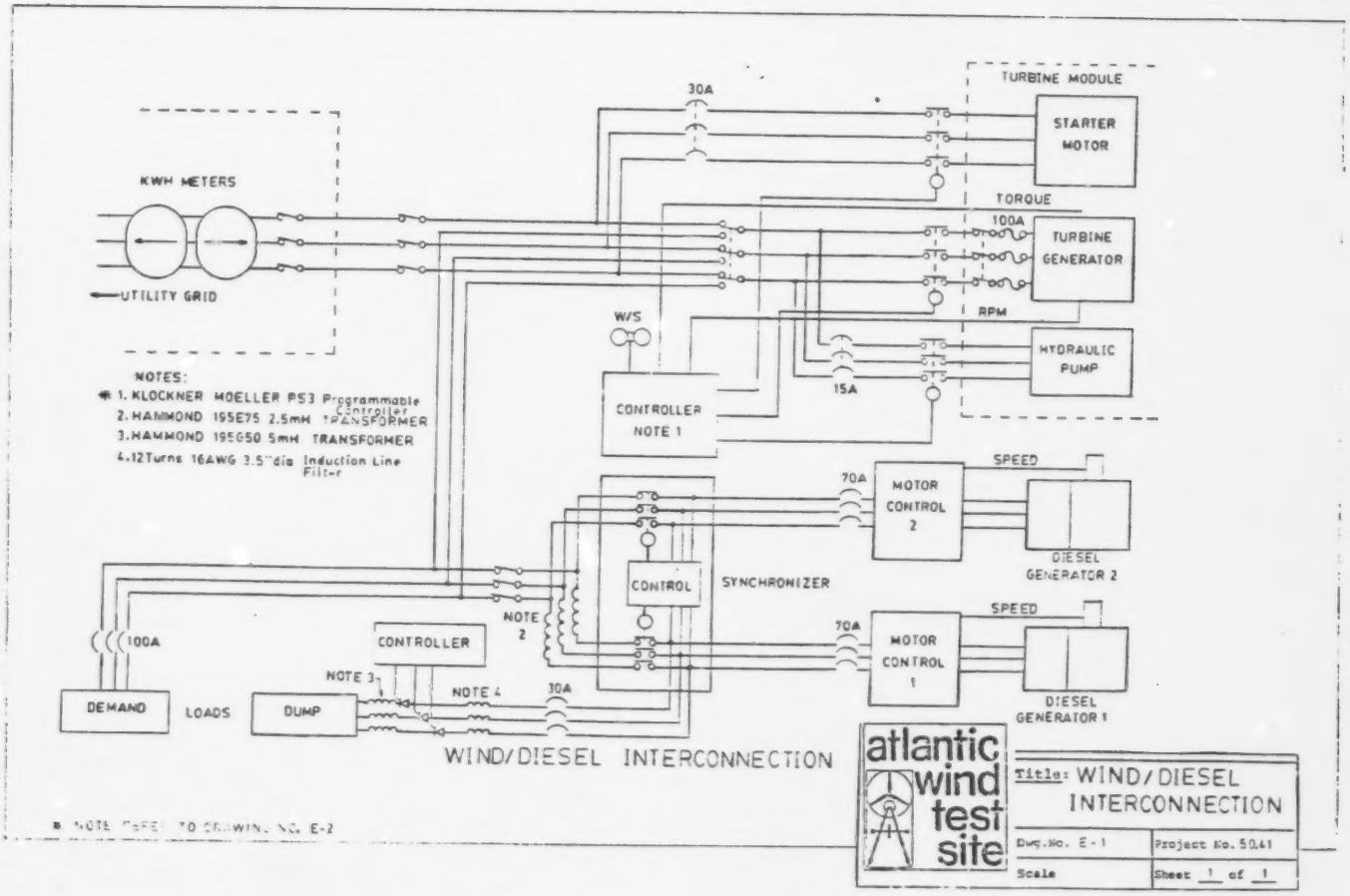


Figure 1. Wind/Diesel Interconnection

The existing guy anchors were relocated to appropriate positions to accommodate the new rotor and guy system. The diesel building was installed on a concrete slab constructed nearby .

Task 6 Order equipment.

Following an inventory of the equipment at Sudbury, additional equipment considered necessary for the installation at AWTS was ordered. Electrical switch gear required to allow utility interconnection and additional instrumentation and mechanical equipment required was procured.

Task 7 Dismantle WECS at Sudbury Site.

This task was carried out by AWTS staff on behalf of Indal Technologies Incorporated (ITI) at their cost.

Task 8 Dismantle diesel generators, switchgear, and auxiliaries at Sudbury Site.

This task was also carried out by AWTS on behalf of ITI at their cost.

Task 9 Load and transport equipment.

The loading of the equipment at Sudbury was supervised and assisted by AWTS personnel. Transport was made by a commercial trucking firm.

Task 10 Off load equipment at AWTS.

The equipment arrived at AWTS in good order and was off-loaded and stored near the installation site while foundations were curing.

Task 11 Install WECS Module and diesel generator sets.

The equipment was installed the foundations as illustrated in Figure(3, 4 & 5). The module was leveled, grouted in and secured. The arrangement of the equipment was altered to allow space inside the diesel building for placement of additional equipment such as flywheel or battery storage.

There some modifications required to the mechanical system since the AWTS wind/diesel system will use only an electrical coupling. The #1 diesel skid, which was connected directly to the wind turbine drive train, was modified. The #1 generator was reversed allowing the existing over-riding cam-clutch, originally installed to separate the wind turbine from the generator, to separate the #1 diesel from its generator. In this manner the

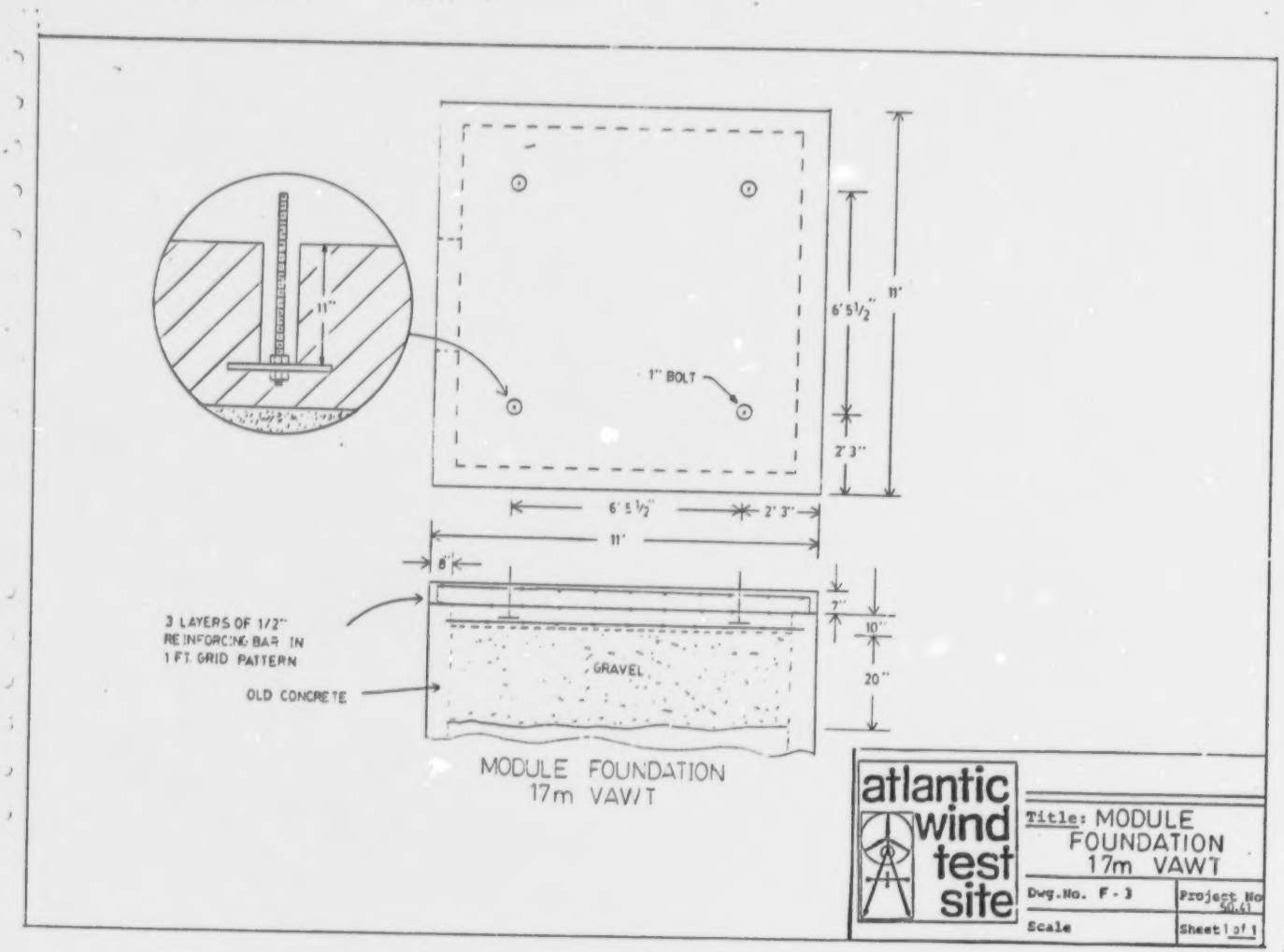


Figure 2. Foundation

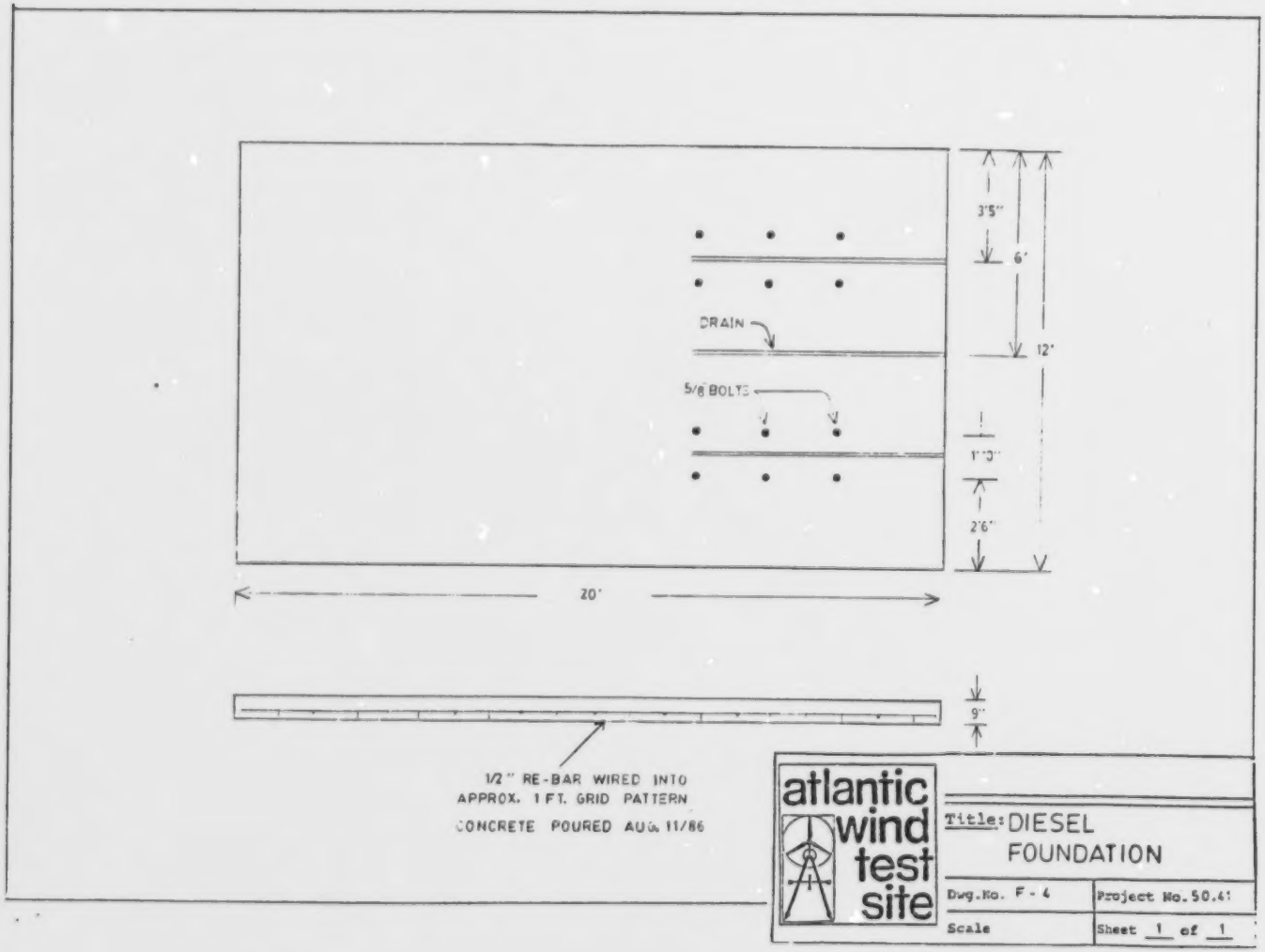


Figure 3. Diesel Shed Foundation

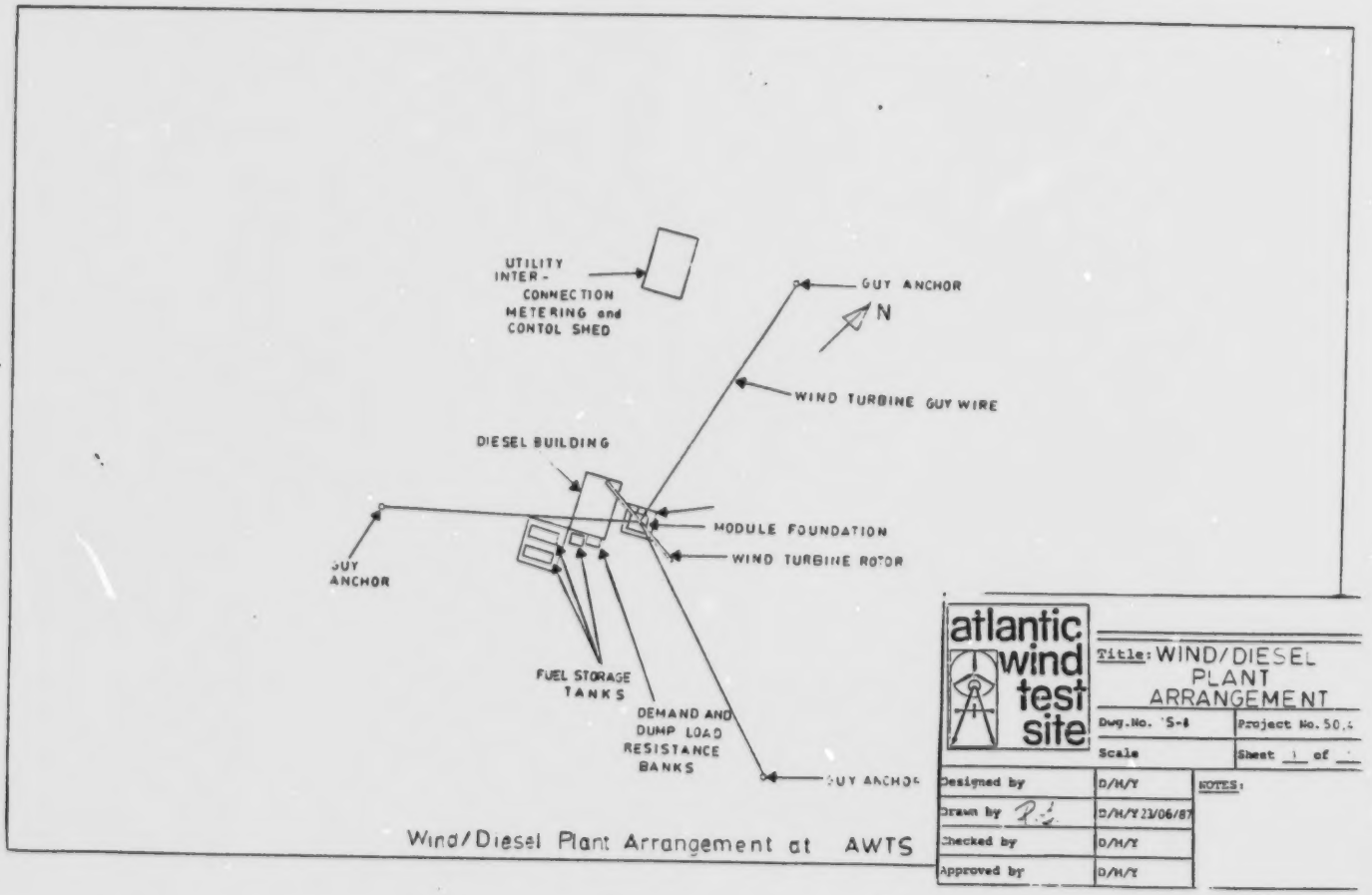

UTILITY INTER-CONNECTION METERING and CONTOL SHED
GUY ANCHOR
N
WIND TURBINE GUY WIRE
DIESEL BUILDING
MODULE FOUNDATION
WIND TURBINE ROTOR
GUY ANCHOR
FUEL STORAGE TANKS
DEMAND AND DUMP LOAD RESISTANCE BANKS
GUY ANCHOR
Wind/Diesel Plant Arrangement at AWTS
atlantic wind test site
Title: WIND/DIESEL PLANT ARRANGEMENT
Dwg.No. S-4
Project No. 50.4
Scale
Sheet 1 of
Designed by D/H/Y
Drawn by D/H/Y 21/06/87
Checked by D/H/Y
Approved by D/H/Y
NOTES:

Figure 4

diesel can be shut down allowing the wind turbine to operate autonomously.

The wind turbine end of the skid was extended to mount the induction generator and then installed in the module.

Task 12 Install switch gear and controls.

The equipment was installed and secured as illustrated in Figure 5.

Task 13 Assemble and erect rotor.

The rotor was assembled using new grade 5 galvanized hardware in the column and blade connections. The blades were assembled using recommended assembly methods.

Two new guys were installed and the third guy shortened to an appropriate length for use. The rotor was erected using a 35 ton crane. All bearings and couplings were aligned and lubricated as required.

Task 14 Connect and interface electrical equipment.

The installation of the electrical equipment was a rather more involved exercise than anticipated due to complexity of the wiring.

The wiring from the generators to the synchronizing and control cabinets and respective loads was reconnected as in the original installation. The utility interconnection for the modified electrical installation at AWTS (Figure 1) was carried out by an electrical contractor and inspected by the provincial electrical inspector.

Task 15 Install and calibrate instrumentation and data acquisition system.

The instrumentation and data acquisition system was installed as illustrated in Figure 6 and signal wiring routed to the appropriate termination location. For control purposes the instrumentation signal wiring is routed to either the module or the wind/diesel control shed as required. The instrumentation for data acquisition and analysis was run from the various signal sources to the control building through underground conduit. Shielded cable was used for analog signals and for digital signals multiconductor wiring used.

The wind speed and power transducers were calibrated. The torque meter was not calibrated since no equipment was available to do

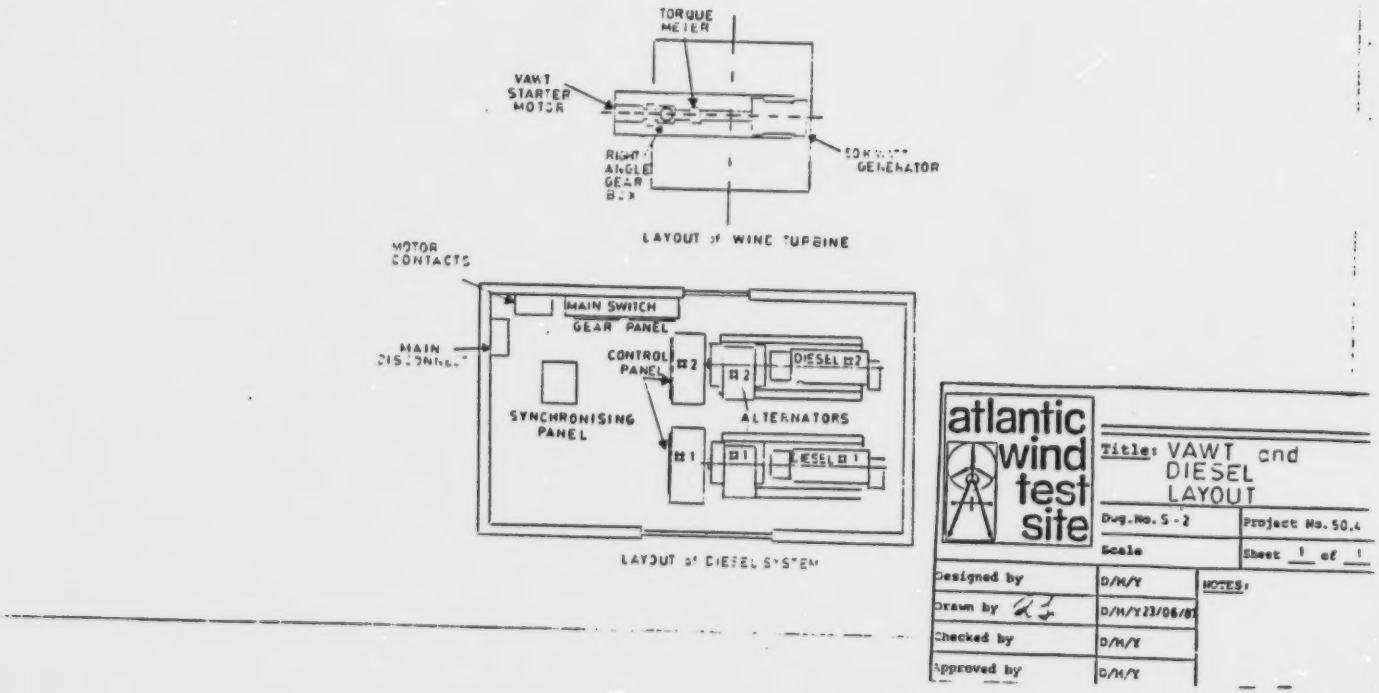

TORQUE METER
VAWT STARTER MOTOR
RIGHT ANGLE GEAR
GENERATOR
LAYOUT OF WIND TURBINE
MOTOR CONTACTS
MAIN SWITCH GEAR PANEL
MAIN
CONTROL PANEL
SYNCHRONISING PANEL
ALTERNATORS
LAYOUT OF DIESEL SYSTEM
atlantic wind test site
Title: VAWT and DIESEL LAYOUT
Dwg.No. S-2
Project No. 50.4
Scale
Sheet 1 of 1
Designed by
D/M/Y
Drawn by
Checked by
Approved by
NOTES:

Figure 5

so. The fuel flow meters were found to be malfunctioning and could not be calibrated. The data acquisition and control system was connected and commissioned. Detailed sketches of the instrumentation and data acquisition system connections are included in Appendix C.

Task 16 Inspect systems and components and prepare as built sketches and documentation.

An inspection of the mechanical, electrical and instrumentation equipment was made following installation. Sketches of the installed equipment and electric and instrumentation diagrams were prepared.

Task 17 Operate and confirm function.

Following installation all components were operated individually to confirm component function. These included the wind turbine, diesel genset #1, diesel genset #2, dump load, and demand loads. Each component had some subsystems that required individual commissioning before component testing could begin. For example, before operation of the wind turbine could be confirmed it was necessary to check the hydraulic system, control system, and generator, etc. All components functioned reasonably well with some minor exceptions which are discussed later.

Task 18 Commence commissioning trials and testing program.
This work was deferred by EMR for future consideration.

Task 19 Operate system for 1000 hours.
This work was deferred by EMR for future consideration.

Task 20 Prepare project report and handbook.

This report completes this task and provides documentation on the equipment.

Task A Purchase and install a 50 HP generator.

Electrical interface design specified a requirement for a 50 HP, 1200 rpm/600v/3 phase induction generator of Class C design having high slip. A refurbished 5% slip motor was obtained and installed on the modified skid inside the wind turbine module (Figure 5).

Task B Provide suitable control shed.

Provision of space for control on disinstrumentation of the system made by rearrangement of equipment in the wind/diesel shed and by an extension of the existing 11M X 17M control

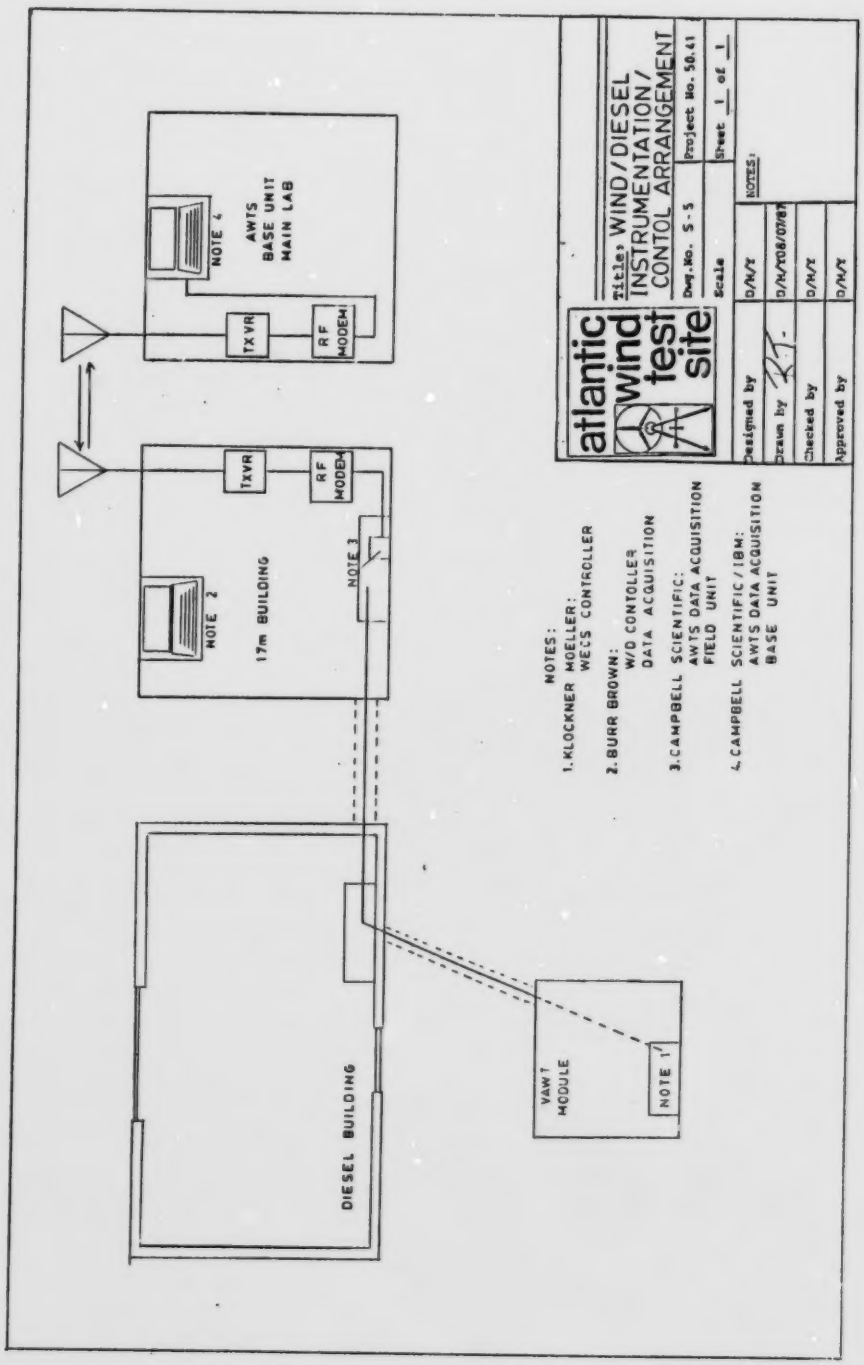

AWTS
BASE UNIT
MAIN LAB
NOTE 4
TX VR
RF
MODEM
17m BUILDING
NOTE 2
TXVR
RF
MODEM
NOTE 3
DIESEL BUILDING
YAW?
MODULE
NOTE 1
NOTES:
1. KLOCKNER MOELLER:
WECS CONTROLLER
2. BURR BROWN:
W/D CONTOLLER
DATA ACQUISITION
3. CAMPBELL SCIENTIFIC:
AWTS DATA ACQUISITION
FIELD UNIT
4. CAMPBELL SCIENTIFIC/IBM:
AWTS DATA ACQUISITION
BASE UNIT
atlantic wind test site
Title: WIND/DIESEL
INSTRUMENTATION/
CONTOL ARRANGEMENT
Dwg. No. S-5
Project No. 50.41
Scale
Sheet 1 of 1
Designed by
D/A/T
NOTES:
Drawn by
D/A/T
Checked by
D/A/T
Approved by
D/A/T

Figure 6

building. The existing 8' X 12' building was extended to 16' to allow adequate room for necessary computing and control equipment.

Task C Design and build controller.

The controller that evolved over successive phases of the Sudbury development work proved to be insufficiently reliable and documented for future wind/diesel development work. A study of available controls systems for this application and selection of a suitable unit was performed.

A description of the controllers considered and the equipment selected is described in Appendix B.

The controls system study recommended the procurement of two systems; a Klockner Moeller PS3-AC, for the wind turbine control, and a Burr Brown PC1 20000 series in conjunction with an IBM-PC compatible computer for the wind/diesel control development system.

The wind turbine control system as installed by Indal Technologies was functional on the wind turbine in Sudbury. This controller was developed by Indal specifically for this model of wind turbine and although it operated accurately and reliably it was not easily modified for development work. The decision to replace the unit was made when the Klockner Moeller PS3-AC (KM-PS3), a small programmable logic controller (PLC), was found that would provide adequate control at low cost. Changes required to the operating logic of the wind turbine for any purpose could be performed quickly and easily on this unit. For instance, the wind speed at which the start up should occur has not yet been determined. With the KM-PS3 the speed set point can be varied in seconds. AWTS staff being unfamiliar with the circuitry of Indal's control system, would be unable to alter the set points as rapidly or accurately. Further, this small PLC has significant implications for grid connected wind turbines by virtue of its low cost. The unit provides adequate analog, digital and frequency inputs and outputs to control nearly any wind turbine. It sells for about $500 which is considerably below most comparable units. This installation provided an ideal opportunity to test the unit in a grid connected application. A description of the Klockner Moeller PC3-AC installation and program is detailed in Appendix D.

A wind/diesel control system has various requirements for different levels of activity. For instance, in a limited penetration wind application where the frequency and voltage of the system are controlled by the diesel/generator, very little sophistication is required of the wind/diesel control system.

However, as wind penetration increases, some control of frequency and possibly voltage may be required. As the development of the technology progresses and additional parameters are added to the wind/diesel system such as short term and intermediate term storage, load management, or wind power forecasting, the requirements of the control system become more complex. The capability of a system to respond to future requirements was a key consideration in system selection.

The Burr Brown PCI-20000 system chosen for this control function is capable, when used with a personal computer and appropriate software, of meeting all control requirements as well as data acquisition and data analysis. The computer, an Everex AT compatible, in conjunction with one of the industry standard software packages "LabTech Notebook" and the PCI-20000 will monitor 32 digital inputs/outputs, 8 analog inputs, 2 analog outputs and 4 pulse counters at high rates for control or data acquisition. Technical information on the modules selected is included in Appendix B.

The capabilities of this system should be adequate to meet future requirements for developments in the technology.

DISCUSSION OF INSTALLATION RESULTS

The equipment has been installed and commissioned in accordance with the objectives of the project and all components have been operated to confirm function. Sketches and descriptions of the installation have been prepared. There are, however, a number of outstanding items to be resolved before the wind/diesel test bed can be considered complete.

The outstanding items can be grouped into two categories: (1) Equipment deficiencies, and (2) Initial operations development. Work to complete the outstanding items were proposed under the project but were deleted from the terms of reference of the contract for the project.

The equipment generally operated quite well, considering the period of inactivity following conclusion of the Sudbury project. Equipment deficiencies, however, have become obvious in several areas. The major problems and deficiencies are described below:

1. The reconditioned induction generator failed after operating for only 30 hours. Early inspection indicate that a failure of the interphase insulation occurred. Cause of the failure has not yet been identified but the unit is still under warranty and it is hoped that the unit can be returned to service with minimal cost to the project.

2. The right angle gearbox, which is located in the wind turbine module, provides 1200 rpm output on two horizontal shafts from the 1000 rpm vertical input from the WECS speed increasers. These shafts are connected on one end to the starter motor and on the other end to the generator. Limited operational experience of the unit to date suggests there may be problems with the long term reliability in present service. The operating temperature of the unit seems higher than desirable. There are also audible resonances in the assembly that seem to be originating from this unit. This has not yet been confirmed. Before long term operation of the wind/diesel system can be commenced the capability of this unit will have to be assessed. Depending on the results of an investigation, the unit may require modification or replacement.

3. The totalizing flow meter used to measure diesel fuel flow rate to the diesel motors is inoperable. The problem has been isolated to a small section of electronic circuitry and the unit should be repairable by the manufacturer for a reasonable cost.

4. The #2 diesel governor has on three separate occasions caused the diesel to overspeed. This seems to be a problem internal to the governor and must be rectified before the unit can be operated safely. The problem may be related to the long period of inactivity and can probably be repaired by AWTS technicians.

5. The dump load, which dissipates excess wind energy to control frequency during autonomous operation was originally controlled by a motor driven variable transformer. The transformer control proved too slow to effectively control the frequency and was replaced by a much faster solid state SCR controller. Although fast response can be obtained with this unit, some concerns have been raised on the effect of electrical harmonics caused by these devices on the system. This problem should be investigated and resolved before long term wind/diesel studies are initiated. If necessary, this problem can be resolved by configuring a multi-element resistive load controlled in a digital manner.

6. The wind turbine is presently being operated in parallel with the utility grid when staff are on site and winds are adequate.

The unit as installed is very noisy. The noise appears related to some resonance in the floor and walls of the steel module. Efforts are being made to dampen these vibrations by installing concrete under and over the floor.

No results are yet available. If this is not successful in reducing the noise level some work will be required to isolate the source of the problem and rectify it.

Initial operations development is required in the areas of control system commissioning and system operation. Work in these two areas were not included in the present contract but is a logical extension of work completed to date and is required to establish the system as a fully operational wind/diesel test bed.

Significant design effort has been put into the selection and installation of the control system and the system installed will serve as a very versatile and powerful control and data acquisition system for further development of wind/diesel technology. Much effort has been spent becoming familiarized with the Klockner Moeller wind turbine controller and its programming requirements and developing control algorithms to enable it to adequately perform as a wind turbine controller. The wind turbine controller is now programmed to reliably and safely control the operation of the wind turbine automatically in all operating circumstances. Considerable additional effort is required, however, to become as familiar with the capabilities of the Burr Brown PCI-20000 system. Some is also required to develop a basic operating algorithm to control the demand and dump loads for the various operating conditions. Once AWTS staff have become familiar with the control system and have the basic algorithms developed for system operation, the various individual wind/diesel components can then be tested as components of a system.

When the capabilities of the control system are fully understood and the various components of the wind diesel system have been operated as a unit the system will be ready as a test bed to continue development of wind diesel technology. It must be recognized that operational problems not detected in the commissioning program to date may become more obvious and as the system is more fully examined. Problems with system dynamics, for instance, were a nuisance at Sudbury and may reoccur in this installation.

CONCLUSION

The project has been completed in general conformance to the contract statement of work. The installed system, as illustrated in Figures 7 and 8, is connected in a manner appropriate for further development work of the wind/diesel concept. As indicated in the earlier sections of this report, some outstanding work caused in part by equipment problems and in part

by work requirements beyond the scope of this contract, remain to be done.

Outstanding work requires some effort to fully assess the extent of the problems and to rectify them. In general the equipment problems seem limited.

The wind/diesel control system now installed, when commissioned and fully operational will provide the Canadian wind energy industry with one of the most advanced development systems for this technology in the world. A further committment of time is required to fully commission the system and to gain familiarization with the system operation and to confirm system functions. When this is done, Canada will again be in the forefront of wind/diesel technology development.

RECOMMENDATIONS

It is recommended that work be continued to more fully commission the wind/diesel system to a level of operation where investigations, design, development, and demonstrations of energy storage, control and load management strategies can be performed. Some basic tasks to achieve this goal are:

1. Investigate the equipment problems already identified in this project and rectify them.

2. Commission and become familiar with the wind/diesel control system for control and data acquisition/analysis purposes.

3. Operate wind/diesel system at various penetrations and determine operational characteristics and compare to those obtained at Sudbury.

4. Develop operating algorithms and operate the wind turbine autonomously. Confirm that operational characteristics conform to those obtained at Sudbury.

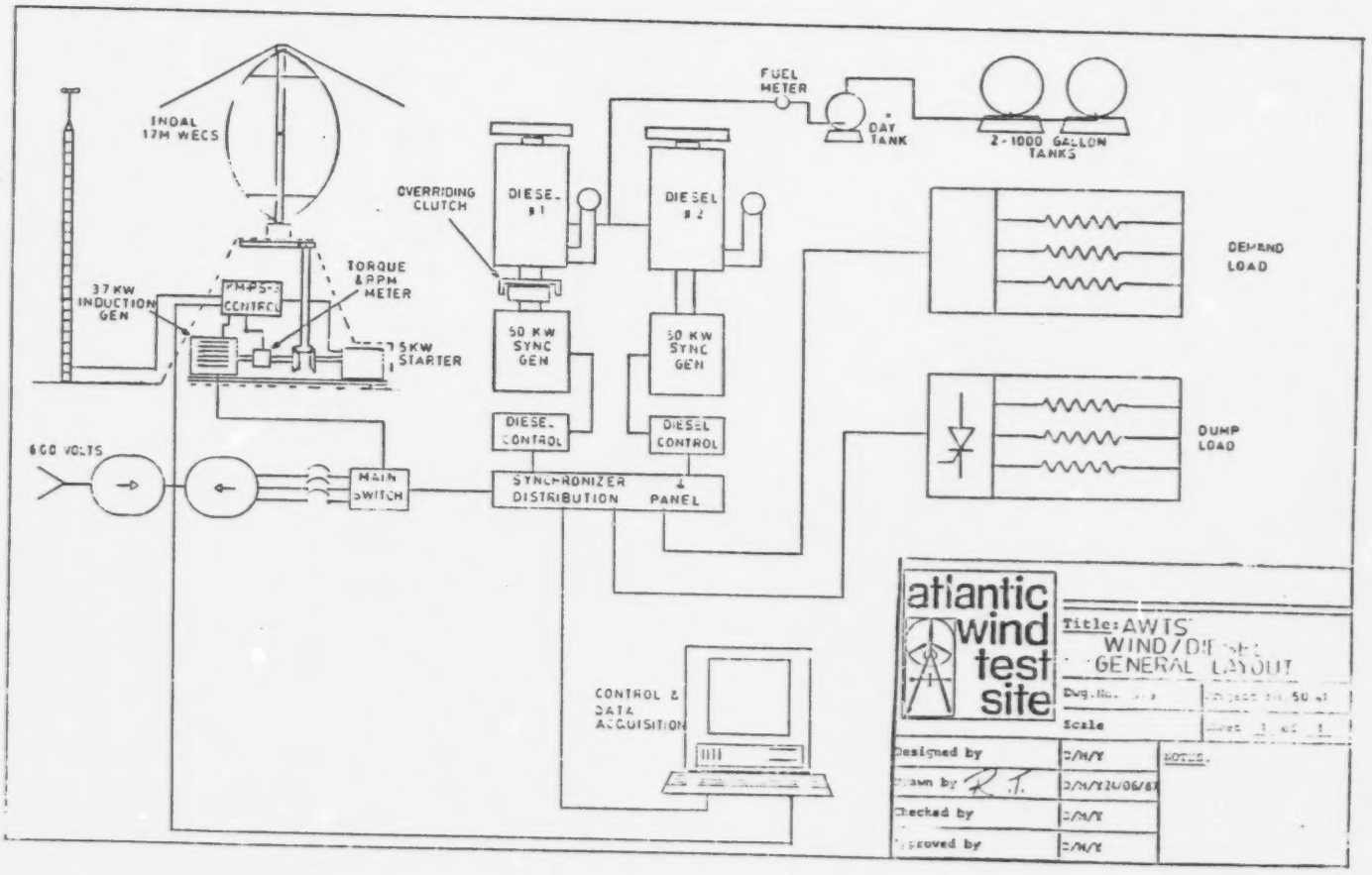


Figure 7. Wind/Diesel General Layout

Wind/Diesel Installation at the
Atlantic Wind Test Site

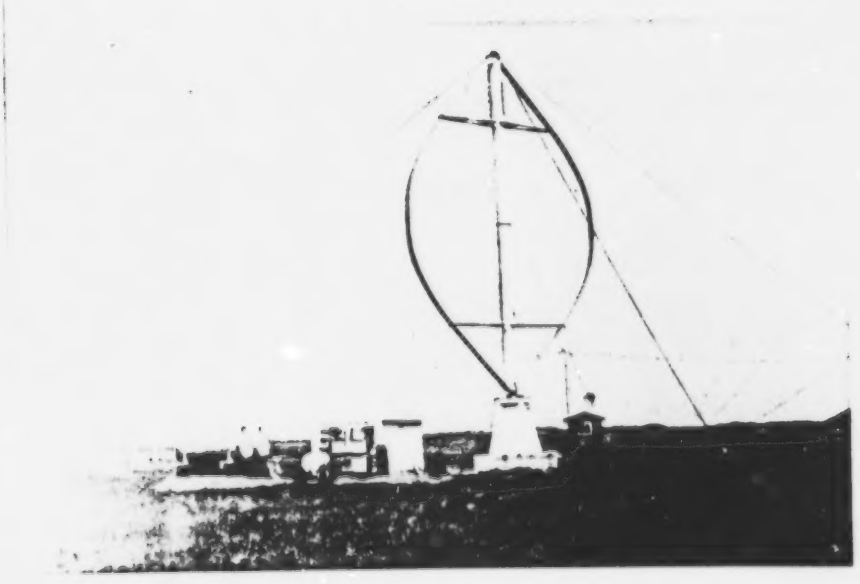


Figure 8

REFERENCES

1. Development, Installation and Testing of a Wind Turbine Diesel Hybrid (Toronto Island Project), L. A. Schienbien, National Research Council Ottawa, January 1979.

2. Sudbury Wind Diesel Report (Sudbury 1), Design, Development and Testing of a Vertical Axis Wind Turbine Assisted Diesel Generator System, L. A. Schienbien, Ontario Ministry of Energy, March 1984.

3. Further Development and Testing of the Sudbury Wind/Diesel Hybrid Power Plant, DAF Indal Ltd., March 1985.

APPENDIX A

ATLANTIC WIND TEST SITE
DATA ACQUISITION SYSTEM

ATLANTIC WIND TEST SITE
DATA ACQUISITION SYSTEM

GENERAL

The AWTS data acquisition system consists of several field located data loggers with on board monitoring and data processing capabilities connected by an FM telemetry link to a base station IBM-AT microcomputer in the main laboratory building (see Figure 1).

The field data loggers are Campbell Scientific CR21 XL microloggers (see Figure 2). These state of the art units are capable of monitoring up to 16 single voltage input channels as well as four pulse input channels. It provides signal conditioning for volts, millivolts, DC/AC resistance, thermistor linearization and RH sensor linearization. It can also provide constant analog output channels, excitation for resistive bridge measurements and six digital control ports to control external devices. The logger can sample a full number of inputs at a preselectable scan rate and either store the raw data or perform preprogrammed standard data processing functions. This data, either raw or processed, may then be stored in final memory for manual interrogation or transmitted to a tape recorder or to a central data storage location.

The IBM-AT is equipped with appropriate software and hardware to enable interrogation of the loggers at the operator's instructions to enable real time data perusal. It is also programmed to automatically retrieve and process the data from the loggers on a daily basis and to retain the results on its 30 megabyte hard disk until the data is examined by site data technician and appended to appropriate test file.

SUMMARY OF OPERATION

The field data loggers are programmed at present to monitor each of the inputs at a one hertz rate and average the values every ten minutes. These ten minute averages are then stored in output locations for later interrogation by the IBM-AT. In addition to routine averages, standard deviations on the windspeeds (one second values) and power output (one minute averages) are calculated. Also, where applicable, software error detection loop is programmed into the logger to raise a flag if data measured is outside predetermined limits.

On a daily basis the IBM-AT is programmed to start automatically and interrogate each of the field loggers in succession and transmit all of the data sorted in their final stage to the AT.

The AT takes the data, combines files from different loggers as required and assigns the combined data to the appropriate file. As an example for any machine under test wind direction, wind speed, temperature and icing conditions from the meterological tower are added to the file for that machine to allow appropriate deletion or adjustment of data (such as when icing occurs) when data is binned at a later point. This results in each file having not only the data specific to a particular machine but also general climatic data from a point on site common to all machines.

The AT also computes the total daily energy production from each machine, the average maximum and minimum windspeed of site anemometers over a 24 hour period, and determines whether the loggers have detected any errors on the machines under test. This information is sent to the printer each morning before AWTS staff arrive.

Once AWTS staff arrive the printer output is examined. Windspeeds that vary from other windspeeds by an unreasonable amount are investigated. Error flags on the logger are checked and if any concerns are raised the problem is investigated.

The energy production as computed by the AT is then compared with the kilowatt hour meter readings taken in each morning's field report. Any substantial discrepancy between the two energy production readings in investigated.

System operation is described in detail in an operator's manual presently being compiled.

DAILY REPORT SEQUENCE

The following describes a typical daily routine to ensure data is reliable and accurate.

A 1. IBM-AT autostarts before site staff arrives and interrogates each logger receiving 144 ten minute averages from each logger.

2. AT then "splits" data to combine appropriate files. (ie. relevant data from the <Met tower is added to 9X6M, Bergery, Adecon files).

3. Data from each unit is stored in a file created for that unit for that day. (ie. 9X6M file for each day will have 144 ten minute averages of time, power, windspeed and pertinent data from Met tower).

4. AT then computes energy produced from each unit, windspeed average, maximum and minimum for each anemometer over the 24 hour period and checks whether the logger has detected errors. This data is sent to the printer.

B 1. Staff arrives on site and checks printer.

2. Anemometers that show unusual averages, maximums or minimums, are investigated. If necessary repairs are carried out and the action is logged.

3. Daily field reports are completed. This involves field investigation of all machines, recording of various readings (kwh, w/s, power), and a general check on the unit.

C Field report is compared with computer printout and any discrepancy is acted upon. Production and operating data is recorded in a daily contract log for each machine and daily reports are filed for future reference.

D The daily file for each machine is inspected by data technician and appended to the appropriate floppy disc for permanent record. This may be done daily or several times a week since there is ample capacity on hard disc to allow several weeks data storage. Data reduction and binning to obtain performance curve on individual machines may also be done on a daily or on a weekly basis.

The general software package to perform binning and statistical calculations and to plot the power curve has been developed. However, each machine that will be tested will require slight modifications to tailor the software to its particular requirements.

CONCLUSION

The AWTS data acquisition system represents state of the art technology which enables AWTS personnel to provide accurate and reliable monitoring on any machine being tested on a 24 hour basis. The accuracy of the measurements is confirmed by the high quality of the equipment, regular calibration of the individual sensors and daily confirmation on the validity of the previous days measurements. The installed system on conjunction with full time qualified staff makes the AWTS one of the leading test sites in any technology in Canada.

IBM Personal Computer AT System Units at a glance

	Base model	Enhanced model
Microprocessor	16/24-bit Intel 80286	16/24-bit Intel 80286
Permanent memory (ROM)	64KB	64KB
User memory (RAM)	256KB standard; expandable to 3MB	512KB standard; expandable to 3MB
Auxiliary storage	1.2MB standard (one 1.2MB diskette drive); expandable to 41.2MB	21.2MB standard (one 1.2MB diskette drive, one 20MB fixed disk drive); expandable to 41.2MB
System expansion	8 expansion slots; one occupied by standard Fixed Disk Drive / Diskette Drive Adapter	8 expansion slots; two occupied by standard Fixed Disk Drive/ Diskette Drive Adapter and Serial/Parallel Adapter
Operating system	IBM Disk Operating System (DOS) 3.00	IBM Disk Operating System (DOS) 3.00

Each IBM Personal Computer AT System Unit offers you program and data storage capacity of up to 41.2MB (42,188,800 characters)—the equivalent of more than 21,000 double-spaced, 8½ by 11-inch typewritten pages of information—with a configuration that includes one 1.2MB diskette drive and two 20MB fixed disk drives.

An enhanced keyboard. The 84-key IBM Personal Computer AT keyboard contains many of the same design features as the familiar, easy-to-use IBM PC Keyboard: adjustable typing angle; standard typewriter layout; 10-key calculator keypad; 10 function keys for activating frequently used commands quickly; and a special "print screen" key for printing out anything that appears on your display screen. In addition, several keyboard design enhancements have been added: The "enter" key, one of the most frequently used keys on the keyboard, has been enlarged and clearly labeled.

- The "shift" keys, used for upper-case letters and special characters, also have been enlarged.
- Labeled green LED indicators on the upper right-hand side of the keyboard light up when you are in the "Number Lock," "Scroll Lock" or "Caps Lock" modes.
- A special keylock on the System Unit secures the keyboard to help prevent unauthorized access to the computer.
- A 3-metre (10-foot) coiled cable allows you to place the keyboard in a convenient working position.

Floor Standing Enclosure. Only the keyboard and display need to be on your desk or workstation. The System Unit can be easily removed from your work space and mounted in a decorative, vertical Floor Standing Enclosure. In most cases, the enclosure will fit under or alongside a desk.

A special keylock on the System Unit helps prevent unauthorized access to the computer.

FIGURE 1

21X MICROLOGGER
CAMPBELL SCIENTIFIC INC.
DURACELL
DURACELL
Interface

FIGURE 2

21X MICROLOGGER

A Rugged, Powerful Little Datalogger

The 21X is a textbook sized, D cell powered precision datalogger. The term "MICROLOGGER" is descriptive of this MICRO-computer based dataLOGGER's MICRO-size, MICRO-power and sub-MICRO-volt sensitivity. It is the combination of a micro-computer, clock, multimeter, calibrator, scanner, frequency counter, controller, and signal generator all in one small box. Small size, low power and the ability to operate in environmental extremes were primary design objectives for portable, remote operation.

SIGNIFICANT FEATURES

PERFORMANCE VERSUS COST: Measurement and processing throughput in excess of 100 channels per second and sensitivity of ½ of a microvolt at 25 channels per second at a remarkably low price.

PERFORMANCE VERSUS SIZE: Sixteen analog and four pulse counting channels plus all the features described here packaged smaller and lighter (including batteries) than the CRC Handbook of Chemistry and Physics.

PERFORMANCE VERSUS POWER CONSUMPTION: Scanning and processing all 16 channels at 1 minute intervals, the 8 alkaline D cells last about 6 months. The rechargeable batteries in the 21XL provide 2 months operation per charge under the same conditions.

SENSITIVITY AND MEASUREMENT SPEED: Fourteen bit precision on 5 software selectable ranges. 0.33 microvolt resolution at 37 milliseconds per channel with 100 nanovolt RMS input noise. At 2.5ms per channel the input noise is 1.2 microvolt RMS.

SENSOR COMPATIBILITY WITHOUT EXTERNAL SIGNAL CONDITIONING: Linearized thermocouple measurements at 7.3 milliseconds per channel resolve to within 0.05 deg. C. Bridge excitation voltage selectable within a ±5 V range at .67 mV resolution. Resistance bridge measurements such as RTDs, load cells, pressure transducers, foil strain gages and thermistors optimize accuracy using AC excitation and ratiometric techniques. AC excitation also minimizes polarization errors in soil moisture, salinity, conductivity, and RH sensors. Four pulse counting channels accommodate magnetic pulse flow meters, photochopped or switch closure devices and incremental shaft encoders directly.

EXPANDABILITY: Analog inputs are expandable in 32 channel increments to a maximum of 192 channels using the Model AM32 Relay Scanner.

REAL-TIME DATA PROCESSING: User programmed processing includes linearization, algebraic and transcendental functions, engineering unit scaling, averaging, maximum minimum, totalizing, standard deviation, wind vector integration with direction sigma, histograms, and more.

REMOTE PROGRAMMING: Programs, parameters and direct commands can be entered directly from the keyboard or via the serial communications port from a remote computer or terminal.

FLEXIBLE DATA STORAGE AND TRANSFER: Data is stored in memory for transfer to the display, cassette, printer, modem, or directly to a computer. Expansion of 21X memory allows storage of up to 19,200 data values. The cassette recorder stores up to 180,000 values on one side of a C60 cassette at a maximum rate of 100 values per second.

ANALOG AND DIGITAL CONTROL OUTPUTS: Two continuous analog outputs with 14 bit resolution are available for strip chart recorders or proportional control. Six digital outputs can be set based on time or processed input levels.

PROTECTED INPUTS AND OUTPUTS: All panel connections are protected from electrical transients using spark gaps or transzorbs.

OPERATION IN HARSH ENVIRONMENTS: -25 to +50 deg. C. 0 to 90% relative humidity. The 21X packaging provides protection from excessive humidity and contaminants. On special order, 21X's will be tested and guaranteed to operate over a -40 to +60 deg. C temperature range.

STANDARD CONFIGURATION

The standard 21X Micrologger includes 16 single ended analog inputs (any pair configurable as a differential input), 4 pulse counting inputs, 4 switched excitation outputs, 2 continuous analog outputs and 6 digital control outputs.

21X processing includes 23 instructions for measurements and control output, 39 instructions for data processing, and 9 instructions for program control.

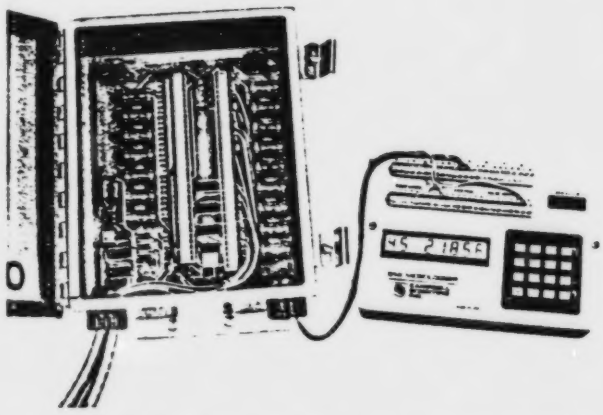
Data storage includes 28 locations for input and user-processed data, 64 locations for intermediate values, and 896 final storage locations. Data storage can be reallocated by the user. Each input location and each intermediate location uses 4 bytes of RAM and each final storage location uses 2 bytes of RAM. All expansion RAM is allocated for data storage.

A 9 pin D type connector on the front panel is used for serial data communication to cassette tape, memory module, modem or printer. It is also used for system programming via remote terminal or computer.

EXPANSION

Analog inputs can be added in 32 channel increments using the Model AM32 Relay Scanner. Up to 6 AM32s can be added for an additional 192 analog channels.

Memory sockets are available on the 21X CPU board allowing the addition of 44K bytes of memory for a total of 64K bytes. An expanded system with 24K bytes of ROM and 40K bytes of RAM can store 19,200 values in the final storage area.



21X Micrologger with the Model AM32 Relay Scanner for channel expansion.

COVER PHOTOGRAPH

The 21X is shown with D cells and some of the directly compatible sensors including a load cell, platinum resistance thermometer, thermocouple, silicon pyranometer and a pressure transducer. Background material is the official CAMPBELL of ARGYLE tartan.

FIGURE 3

SPECIFICATIONS

The following electrical specifications are valid for an ambient temperature range of −25 deg. C to +50 deg. C unless otherwise specified.

ANALOG INPUTS

NUMBER OF CHANNELS: 8 differential or up to 16 single ended using one differential channel for each two single ended channels.

CHANNEL EXPANDABILITY: The Model AM32 Relay Scanner multiplexes 32 differential channels through a single 21X differential channel. Up to 6 AM32 scanners can be added to a 21X for 192 additional analog channels.

VOLTAGE MEASUREMENT TYPES: Single-ended or differential. A thermistor at the input terminals provides reference junction compensation for thermocouple measurements.

ACCURACY OF VOLTAGE MEASUREMENTS AND ANALOG OUTPUT VOLTAGES: 0.1% of FSR, 0.05% of FSR (0 to 40 deg. C).

RANGE AND RESOLUTION: Ranges are software selectable for any channel. Resolution for single ended measurements is twice the value shown.

Full Scale Range	Resolution
±5 volts	333. microvolts
±0.5 volts	33.3 microvolts
±50 millivolts	3.33 microvolts
±15 millivolts	1. microvolt
±5 millivolts	0.33 microvolts

INPUT SAMPLE RATES: The fast A/D conversion uses a 250us signal integration time and the slow conversion uses a 16.666ms signal integration time (one power line cycle period). Differential measurements include a second sampling with reversed input polarity to reduce thermal offset and common mode errors. The following intervals do not include the self-calibration measurement which occurs once per instruction. Input sample rates should not be confused with system data throughput rates.

Fast single-ended voltage:
2.4 milliseconds/channel
Fast differential voltage:
3.7 milliseconds/channel
Slow single-ended voltage:
18.8 milliseconds/channel
Slow differential voltage:
37.0 milliseconds/channel
Fast differential thermocouple:
7.3 milliseconds/channel

INPUT NOISE VOLTAGE:
Fast differential — 0.83 microvolts RMS
Slow differential — 0.1 microvolts RMS

COMMON MODE RANGE: ±5 volts.

COMMON MODE REJECTION: >140 dB (DC to 100 Hz).

NORMAL MODE REJECTION: 70 dB (60 Hz with slow differential measurement).

INPUT CURRENT: 2 nanoamps max.

INPUT RESISTANCE: 200 gigohms

ANALOG OUTPUTS

NUMBER OF ANALOG OUTPUTS: 4 switched, 2 continuous.

DESCRIPTION: Switched and continuous. A switched output is active only during a measurement and is switched off (high impedance) immediately following the measurement. Only one switched output can be active at any one time. The 2 continuous outputs hold a preset voltage until updated by an analog output command.

RANGE: ±5 volts.

RESOLUTION: 0.67 millivolts.

ACCURACY: Same as voltage input.

OUTPUT CURRENT: 20 mA at ±5 volts, 50 mA at ±2.5 volts.

RESISTANCE AND CONDUCTIVITY MEASUREMENTS

ACCURACY: 0.035% (0.02% 0 to 40 deg. C) of full scale bridge output provided the matching bridge resistors are not the limiting factor. The excitation voltage should be programmed to match the bridge output with a full scale input voltage range.

MEASUREMENT TYPES: 6 wire full bridge, 4 wire full bridge, 4 wire, 3 wire and 2 wire half bridge. High accuracy, low impedance bridge measurements are ratiometric with dual polarity measurements of excitation and output to eliminate thermal emfs. AC resistance and conductivity measurements use a 750us excitation pulse with the signal integration occurring over the last 250us. An equal duration pulse of opposite polarity is applied for ionic de-polarization.

PULSE COUNTERS

NUMBER OF PULSE COUNTER CHANNELS: 4 eight bit or 2 sixteen bit, software selectable.

MAXIMUM COUNT RATE: 2550 Hz, eight bit counters; 250 kHz, sixteen bit counters. Pulse counter channels are scanned at a maximum rate of 10 Hz.

MODES: Programmable modes are switch closure, high frequency pulse and low level AC.

SWITCH CLOSURE MODE
MINIMUM SWITCH CLOSED TIME:
3 milliseconds.
MINIMUM SWITCH OPEN TIME:
4 milliseconds.
MAXIMUM BOUNCE TIME:
1 millisecond open without being counted.

HIGH FREQUENCY PULSE MODE
MINIMUM PULSE WIDTH:
2 microseconds.
MAXIMUM INPUT FREQUENCY:
250 kilohertz.
VOLTAGE THRESHOLDS.
The count is incremented when the input voltage changes from below 1.5 volts to above 3.5 volts.
MAXIMUM INPUT VOLTAGE:
±20 volts.

LOW LEVEL AC MODE
This mode is used for counting frequency of AC signals from magnetic pulse flow transducers or other low voltage, sine wave outputs.

MINIMUM AC INPUT VOLTAGE:
6 millivolts RMS
INPUT HYSTERESIS:
11 millivolts.
MAXIMUM AC INPUT VOLTAGE:
20 volts RMS.
FREQUENCY RANGE.

AC Input Voltage (RMS)	Range
6 millivolts	1 Hz to 100 Hz
10 millivolts	0.5 Hz to 1000 Hz
20 millivolts to 20 volts	0.3 Hz to 2000 Hz

(consult factory if higher frequencies are desired)

DIGITAL CONTROL OUTPUTS

The 21X includes 6 digital control outputs that can be set or reset on command.

OUTPUT VOLTAGES
(no load): High — 5 volts ± .1 volt.
Low — < 0.1 volt.

OUTPUT RESISTANCE.
400 ohms.

TRANSIENT PROTECTION

All input and output connections are protected using spark gaps connected directly to a heavy copper bar on the circuit card between the two input terminal strips. The 12 volt power input and charger inputs are protected with transzorbs.

CPU AND INTERFACE

PROCESSOR: HITACHI 6303 CMOS 8 bit microprocessor.

MEMORY: 16k ROM, 4k RAM, expandable in increments of 8k of RAM or ROM up to a total of 64k. Standard 21X stores 896 low resolution data points in Final Memory, 19,200 data points with fully expanded RAM.

DISPLAY: 8 digit LCD (0.5" digits).

PERIPHERAL INTERFACE: 9 pin D-type connector on the panel for connection to cassette recorder, modem, printer, or RS232 adapter. The serial interface can be programmed for baud rates of 300, 1200, 9600 and 76,800.

CLOCK ACCURACY: ±1 minute per month.

MAXIMUM PROGRAM EXECUTION RATE: The 21X Programming Table can be executed in sync with real time at a maximum rate of 80 per second. Typical throughput rates allow 1 measurement with linear scaling and transfer to tape at this rate with no interruption.

SYSTEM THROUGHPUT: Data throughput is the rate at which a signal can be measured, processed and stored in Final Memory. The rate is reduced by additional processing or when data is transferred to Cassette Tape or through the 21X serial port.

Throughput to the cassette tape is 100 data values per second. During tape transfer, 25% of the CPU's time is required. Therefore, program execution is uninterrupted if the user-entered program requires less than 75% of the CPU's time.

ASCII data values (10 characters per value) can be transmitted via the serial port at 9600 baud with a throughput of approximately 100 values per second with 15% CPU utilization. Faster throughput rates are possible if CSI's binary format is transmitted (consult factory).

Each time a new measurement instruction is specified, time for two additional measurements is required for self-calibration. Therefore, using more repetitions in fewer instructions increases throughput.

SYSTEM POWER REQUIREMENTS

VOLTAGE: 9.6 to 15 volts.

TYPICAL CURRENT DRAIN: 1.0 mA quiescent, 25 mA during processing, and 60 mA during analog measurement.

INTERNAL BATTERIES: 8 Alkaline D cells with 7 amp hour capacity. The Model 21XL includes sealed lead acid batteries with 2.5 amp hour capacity per charge.

EXTERNAL BATTERIES: Any 12 volt external battery can be connected as a primary power source with the internal batteries providing backup while changing external batteries.

OPERATION FROM OTHER SOURCES: The Model 21XL includes a battery charging circuit that can be connected to 15 to 30 VDC indefinitely to maintain a full charge on the batteries without degradation. The charging circuit includes temperature compensation for maintaining optimum charging voltage at temperature extremes. A 110 VAC to 16 VDC wall transformer is provided with the 21XL.

PHYSICAL SPECIFICATIONS

SIZE: 8.2" X 5.7" X 3.3". Input terminal strips extend 0.45" above the panel surface.

WEIGHT: 6.2 lbs.

Reprinted October 1984

FIGURE 4

APPENDIX B

WIND/DIESEL CONTROL SYSTEM INVESTIGATION

WIND/DIESEL CONTROL SYSTEM INVESTIGATION

SUMMARY

The investigation into a control system for the wind/diesel system at the Atlantic Wind Test Site has been completed. It is recommended that an IMB-PC compatible computer, Burr-Brown industrial interface and Labtech Notebook software be purchased to provide adequate digital and analog control, and data acquisition and to meet the criteria for wind/diesel development over the next few years. Total cost of this equipment will be around $12 000. It is also proposed to purchase a Klockner Moeller PS3 minicontroller to perform control on the wind turbine during utility operation. Cost of this unit including controller and simulator will be less than $1 000. Total proposed budget will not exceed the original estimate of slightly more than $14 000.

INTRODUCTION

The project to move the wind/diesel development system from Sudbury to the Atlantic Wind Test Site has progressed to a point where final mechanical and electrical assembly is imminent. One of the major outstanding tasks for this project is the selection, acquisition and installation of a controller to allow the system to operate in a safe reliable manner while monitoring and controlling all necessary functions.

CONTROL SYSTEMS STUDIED

The control system installed in Sudbury was developed over the period of the original test by Indal Technologies. Although functional, it was poorly documented, rather complex and considered marginally adequate for further development of the wind/diesel concept. Because of the obvious limitation in the existing system and the considerable development over the past several years in digital control technology, it was agreed a digital control system based on state of the art technology would be acquired.

Two concepts of control systems were examined for our wind/diesel application. The first was the programmable logic controllers (PLC'S) that are becoming prevalent throughout industry. These units are available in a wind range of sizes and capabilities and are marketed by most major electrical manufacturers. Among the

units investigated were Westinghouse, Gould and Allen Bradley, as well as several others. The systems investigated were programmable using an IBM-PC with appropriate software or by using a hand-held programmer supplied with each controller. the second concept uses an IBM-PC or equivalent in conjunction with interface cards, which translate field inputs into signals familiar to the computer and a software package to perform the actual intelligent control. Among the suppliers of this concept are Burr-Brown, Action Instruments, Opto 22 and a large number of less well known companies.

SYSTEM OBJECTIVES

The two concepts were evaluated giving general consideration to the following:

1. Competency; the system must have the capability to perform the immediate and foreseeable future control requirements with adequate accuracy, speed and reliability.

2. Ease of programming; A controller that is easy to program can improve cost effectiveness substantially. Software generation and learning new languages is very time consuming and expensive.

3. Flexibility; the wind/diesel system is to be installed so that development work can be done by any Canadian organization that wishes to do so. The ability of a control system to be easily integrated with existing utilities (telecommunications, data acquisition, dynamic analysis) could prove valuable in future development.

4. Cost; inevitably this becomes a key consideration in any system selection.

SYSTEM PROS AND CONS

1. PLC'S

To varying degrees all PLC'S exhibited similar characteristics. On the positive side they all offer excellent reliability, they have well documented accuracy and speed capabilities, which are quite adequate and they are relatively easy to program using simple ladder logic. For present and probable future requirements, they are quite capable of performing the functions.

However, they are generally expensive, especially if a system marginally sized needs to be upgraded in the future. (This is not as predictable as it might seem; a relatively straight forward installation at a local utility, for instance, is presently underprogrammed due to memory limitations.) Future programming requirements for the wind/diesel controller is unknown at this point and if sophisticated algorithms are developed the PLC'S may not be capable, without expensive upgrades, to perform the required functions. Another drawback of the PC'S is the lack of flexibility in integrating them with standard computer programs which presently exist or could be developed in the future. Remote data acquisition, spectral analysis or performance monitoring may not be possible.

In some instances software to make PLC'S programmable by IBM-PC are quite expensive. Also a PID algorithm which might prove helpful for our control applications is not available on all controllers and is an expensive option on most others.

2. MICROCOMPUTER BASED CONTROLLERS

There are many suppliers of equipment to interface between IBM-PC or other microcomputers and field devices. Most of these signal conditioning modules can take a variety of digital or analog inputs and usually fit in one of the computer's expansion slots. The computer can control these inputs and outputs by custom generated software or by using any of a number of available software programs of varying complexity and cost. The computer usually operates fulltime as a controller, but with a multi-tasking operating system or a smart control board having on board programming, the computer can control the functions in a supervisory capacity yet retain its power for a number of other applications.

This equipment is very flexible in that much of the software available to control the operation is compatible with existing software for processing data (ie. Lotus 1-2-3), and many software packages include options for high speed data acquisition, dynamic analysis, etc.

Programming this type of software can be done in any of the major languages or in simple menu control methods which should simplify computer programming. Having a system operating via an IBM or compatible also increases the ease with which the package can be integrated into other research organizations or private companies wanting to modify software, access data, etc., using a modem connection.

The cost of these packages including a microcomputer is similar to some of the PLC'S we have considered.

The limitation of this sort of system is the lack of wide spread application references locally, and concern for service should problems develop. However, these systems are available from well established companies (ie. Burr-Brown, Octo 22) and represented by reputable suppliers in Canada (Transduction, Allan Crawford).

SYSTEMS

The following is a list of the systems considered based on an evaluation of the manufacturers hardware and discussions with the manufacturers:

1. PLC'S

a) Westinghouse

Numalogic PC-1100-10-3-3	$2 300
2 - NL-1005 ($250 ea) 8 channel digital input	500
2 - NL-1020 ($390 ea) 8 channel digital output	780
1 - NL-1050 8 bit, 8 channel A/D	450
1 - NL-1057 8 bit, 4 channel D/A	1 280
Rack	230
Software	900
Total	$6 440

This is the least expensive PLC option. These prices include only 8 bit A/D and D/A resolution, and 2-5k memory. Some discount (about 10%) would be available.

b) Gould

884A Processor (2k memory)	$2 645
24V Power Supply	1 700
16 - 120V DC input	595
16 - 120V AC output	845
8 - Analog A/D input	2 235
8 - Analog D/A output	2 705
Rack 27"	890
Total	$11 615

This is substantially more expensive than Westinghouse due in part to higher resolution A/D and D/A and separate power supply price (24 DC).

c) Allen Bradley PC205

1772LS Processor	$1 130.50
Chassis	755.65
Power Supply	773.50
16 Channel Digital Input 120V AC	398.55
16 Channel Digital Output 120 V AC	595.00
8 Channel, 8 Bit A/D	987.70
4 Channel, 12 Bit D/A	1 606.50
Total	$6 247.70

Software

IBM-PLC Interface	$2 189.60
Universal Interface	595.00
Program Development	1 784.00
Cable	214.00
1784-C75-IBMKG	89.25
Total	$4 871.85

Total	$11 119.25
PID Algorithm	2 860.00
TOTAL	$13 979.25

Allen Bradley is competitive from a hardware standpoint. Software is very expensive.

b) Klockner-Moeller PS

This mini-PLC is the most inexpensive unit investigated. Most mini-PLC'S are capable of only performing digital I/O. The PS3 can take 16 digital inputs with 8 digital outputs. One remarkable thing about this controller is that it can also take four analog an one counter inputs and provide one analog output. The most remarkable thing about this controller is the price ($500). A hand-held programmer costs $300.

This system can easily control the start/stop operation of the wind turbine and with its own analog output could conceivably control the dumpload and therefore operate autonomously. However, it is a low cost controller which is simply not adequately powered for such service as it will ultimately see.

2. Microcomputer Based Controllers

a) Action Instruments (marketed by CTH Instruments, Dartmouth, NS)

Using CIMPAK, a process measurement and control package with multi-tasking capabilities that easily meets our needs.

CIMPAC Software	$1 600
A104 Analog I/O	1 360
Digital Input	600
Digital Output	600
Total	$4 160

This does not include field interface relays, wiring, cabinets or IBM PC compatibles.

b) Opto 22 (marketed by Transduction Ltd., Mississauga, ON)

Analog PB16MA	$ 559
6 - Analog In (6 X 55)	330
4 - Analog Out (4 X 138)	552
Analog board	
Digital 16 Input	605
Digital 16 Output	605
	$2 651
PIDware & Optoware	500
Total	$3 151

This seems to be the most inexpensive method of monitoring all inputs. Note: This does not include panels, cabling, etc., or the purchase of an IBM compatible computer.

c) Burr-Brown (marketed by Allen Crawford Associates)

PCI 20001-C-2 carrier card with 32 bit digital I/O 8 channel differential analog input, 12 channel analog output, 4 channel counter card, including all cabling, interface relays and panels to complete system (see attached) except for IBM compatible computer. $5 589

LabTech Notebook Software	450
Total	$7 239

CONCLUSIONS AND RECOMMENDATIONS

A study of the available control systems confirms that cost and capabilities of control technology has improved dramatically in the past several years. The improvement in the ease of programming should substantially improve productivity in the development of the wind/diesel concept.

Evaluating the pros and cons of the various systems suggests that using a microcomputer based system is the best option in terms of future expandability, ease of programming, data analysis and report generation. A fully assembled system of this type is more expensive than a PLC but we feel the additional expenditure is easily justified.

It is proposed to purchase the Burr-Brown system of field interface devices, an IBM compatible computer and Labtech Notebook software. The key to this recommendation is the capability of the Labtech Notebook software. It is capable of meeting all control requirements for either digital control of wind turbine operation or PID control of frequency or voltage in autonomous operation. It is also powerful enough to accommodate future expansions and program development with little additional cost. For instance, if we wish to program the controller for use in short or long-term storage work or in work to eliminate torque ripple, it is easily powerful enough to do it. A PLC probably would not be equally versatile. An added benefit is the flexibility and ease of programming that will enable other parties interested in doing wind/diesel development work to easily reprogram the system. The high speed data acquisition and dynamic analysis is very helpful and the fact that the program can be easily integrated into Lotus 1-2-3 means report generation and data manipulation becomes much easier and faster.

Total cost for the purchase of this system complete with IBM-PC compatible computer will be around $12 000 with taxes.

This system will have the capability of fully meeting the requirements of the wind/diesel system for the foreseeable future. It is anticipated that future work on the wind/diesel system will be conducted over period of time to conduct specific tests. Much of the time the system will not be used. The turbine, however, will be utilized continuously as a utility interconnected unit. To avoid using the wind/diesel control system for controlling utility interconnection, it is proposed to purchase a Klockner Moeller PS3 mini-PLC. There are several reasons to purchase this controller; first, the main control package can be used for programming or data manipulation without any fear of affecting the machine's operation. More important is the significance of this low cost controller. If this will control a grid-connected wind turbine, it represents a manor cost reduction in wind turbine control systems. At around $500 it reduces controller costs by several hundred percent. The evaluation of the controller will perform a valuable service to the wind energy industry in Canada. Appendix includes technical information on the recommended controllers.

DESCRIPTION

Increase Productivity in the Lab with LABTECH NOTEBOOK

When interfaced with analysis programs such as Lotus 1-2-3, Symphony, or RS/1, LABTECH NOTEBOOK increases laboratory research productivity the same way personal computers increase productivity for the office. LABTECH NOTEBOOK, an integrated, general-purpose software package for data acquisition, process control, monitoring, and data analysis runs on the IBM PC, XT, or AT, and other PC compatibles. It requires a data acquisition hardware interface. Because of its fast and easy-to-use menu system, NOTEBOOK requires no programming.

LABTECH NOTEBOOK allows the personal computer to be used for other PC programs while collecting data. After initiating a run, the user may run another program, while NOTEBOOK continues collecting data. When this program is completed, the graphic displays are updated with the data which was collected during background operation. This foreground/ background capability means the computer can be used for other functions during long tests.

Because LABTECH NOTEBOOK is menu-driven and extremely easy to learn and use, it requires no computer skills on the part of the operator. Each data acquisition run may be set up differently or as previously specified, depending on the type of test. NOTEBOOK displays the setup conditions which define the current run so that they may be easily modified. The user may save all of the setup conditions pertaining to a run and recall them later.

LABTECH NOTEBOOK can reduce complicated procedures to single-button operations, so that repetitive tests, process control and monitoring activities are greatly simplified. It includes a programming function for those who wish to customize or automate repetitive data acquisition, process control or graph generating procedures. This option uses MAGIC/L, an incrementally compiled language, included in LABTECH NOTEBOOK.

Although the program is very user-friendly, it does not sacrifice any of the performance potential of the hardware it supports. Data can be collected at the maximum rates supported by the hardware interface. Data can also be collected at very slow rates, with runs lasting weeks or months if the user desires.

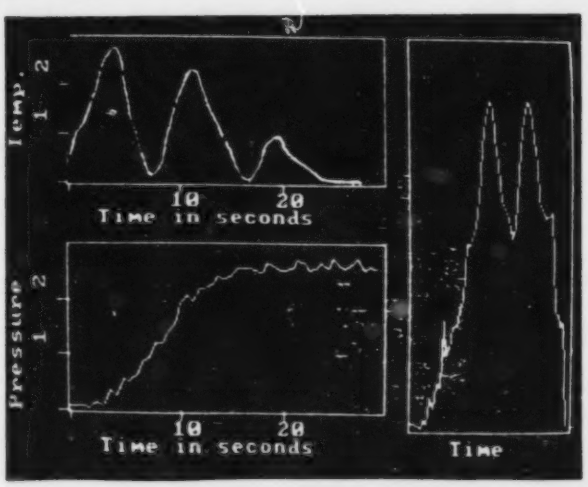
Flexibility is a key feature of LABTECH NOTEBOOK. To this end, each channel can be set up with different characteristics. Sampling rates may vary from channel to channel, and the sampling rate may vary for each channel at different times during a run. Data acquisition may take place as soon as the program starts, or may be triggered by an external source. NOTEBOOK's data monitoring and filing capabilities are equally versatile.

For control functions, open and closed-loop control algorithms are readily implemented. In open-loop mode, the user defines one period of any imaginable waveform; the signal is then clocked out automatically during the run. For closed-loop control, PID (proportional-integral-derivative), "bang-bang" (on/off), and "alarm" loops can be set up.

LABTECH NOTEBOOK includes two sophisticated analytical routines: non-linear curve-fitting, and Fast Fourier Transforms (or FFTs). These programs are designed to take advantage of the time saving 8087 or 80287 floating point processors, if they are present in the PC, but do not require them. The curve-fit function uses an iterative routine (Powell's Method) to fit an arbitrarily complex model (up to 10 parameters and 10 independent variables) to the collected data. The FFT function provides a powerful tool for signal processing analysis, accommodating both real and complex input waveform data. In addition, the FFT function can be used to calculate power spectra. Power spectra may be displayed in either linear or logarithmic units.

By interfacing LABTECH NOTEBOOK with an analysis program or spreadsheet such as Lotus 1-2-3, Symphony, or RS/1, the user may go from data collection to the final report without ever writing down or keying-in a single piece of data. Data files may be automatically imported into a worksheet or table for reduction and analysis (integration, differentiation, logarithmic conversion, etc.), statistical comparisons, and preparation of publication-quality graphics. Depending on the software chosen, data-base management and word processing are also available.

A tutorial section of LABTECH NOTEBOOK demonstrates how data acquisition can be set up and run. A software simulation of an analog to digital converter creates a real-time display of a data file without a hardware interface installed. The novice can learn how to set up an acquisition run, analyze, reduce and graph the data. Additionally, NOTEBOOK's features can be evaluated without committing to a specific hardware interface.



LABTECH® NOTEBOOK

PCI-4904-1

BURR-BROWN®

LABTECH NOTEBOOK is marketed by Burr-Brown for use with its PCI-4000 Intelligent Instrumentation Systems.

Software for Data Acquisition, Control and Analysis

FEATURES

- No programming required
- Data acquisition — supports a wide variety of hardware interfaces
- Process Control — open or closed loop
- Thermocouple linearization and compensation
- Real-time graphic display of data
- Continuous writing of data to disk during data acquisition
- Foreground/Background Operation — run other PC programs during data acquisition and control
- Automatically uses 8087 or 80287 floating point processors, for speed in computation, if installed
- Menu-driven software — in the style of popular spreadsheets
- Programming option — to allow automation of experiments/tests
- Advanced non-linear curve fitting function
  - — up to 10 parameters and
  - — up to 10 independent variables
  - — fits to transcendental functions
- Fast Fourier Transforms
  - — real and complex waveforms
  - — supports both forward and inverse FFTs
- Interfaces to other programs — for analysis, file management and graphics — programs such as Lotus 1-2-3™, Symphony™, or RS/1™
- Complete tutorial — includes software simulation of an analog to digital converter for demonstrating LABTECH NOTEBOOK's features
- On-line HELP screens
- For IBM PC, XT or AT, and compatibles

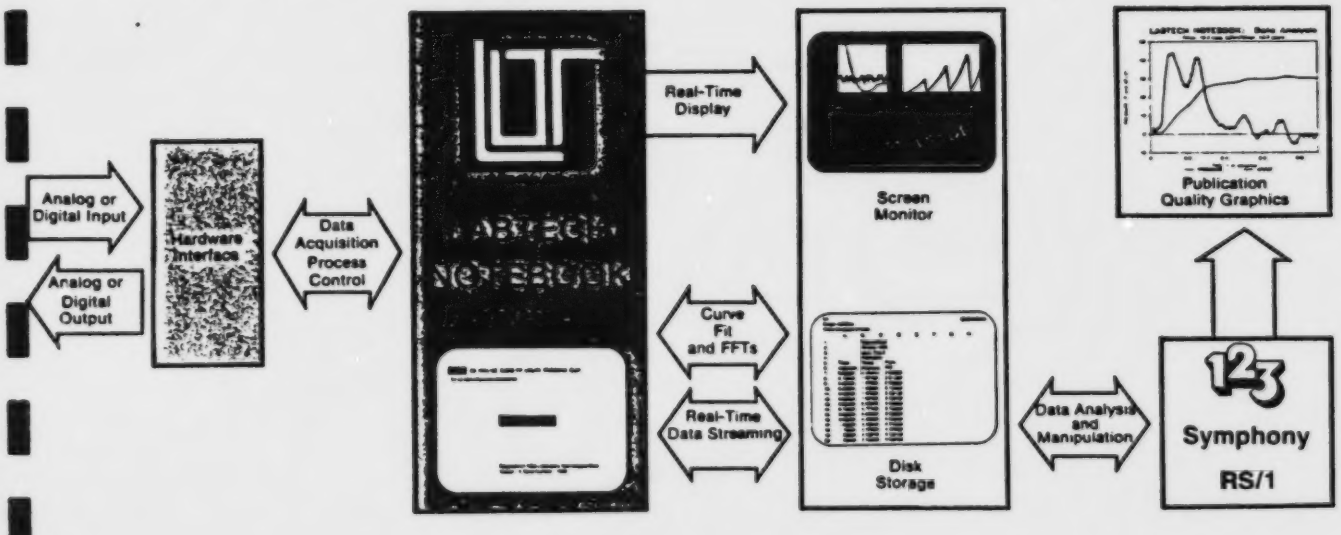


Figure 1. A Functional Diagram of LABTECH NOTEBOOK

LABTECH® is a registered trademark of Laboratory Technologies Corporation.

IBM is a registered trademark of International Business Machines, Inc. Lotus 1-2-3™ and Lotus Symphony™ are trademarks of Lotus Development Corporation. RS/1™ is a trademark of BBN Software Products Corporation. MAGIC/L™ is a trademark of Loki Engineering, Inc.

Copyright (C) 1984, Laboratory Technologies Corporation, Cambridge, MA.

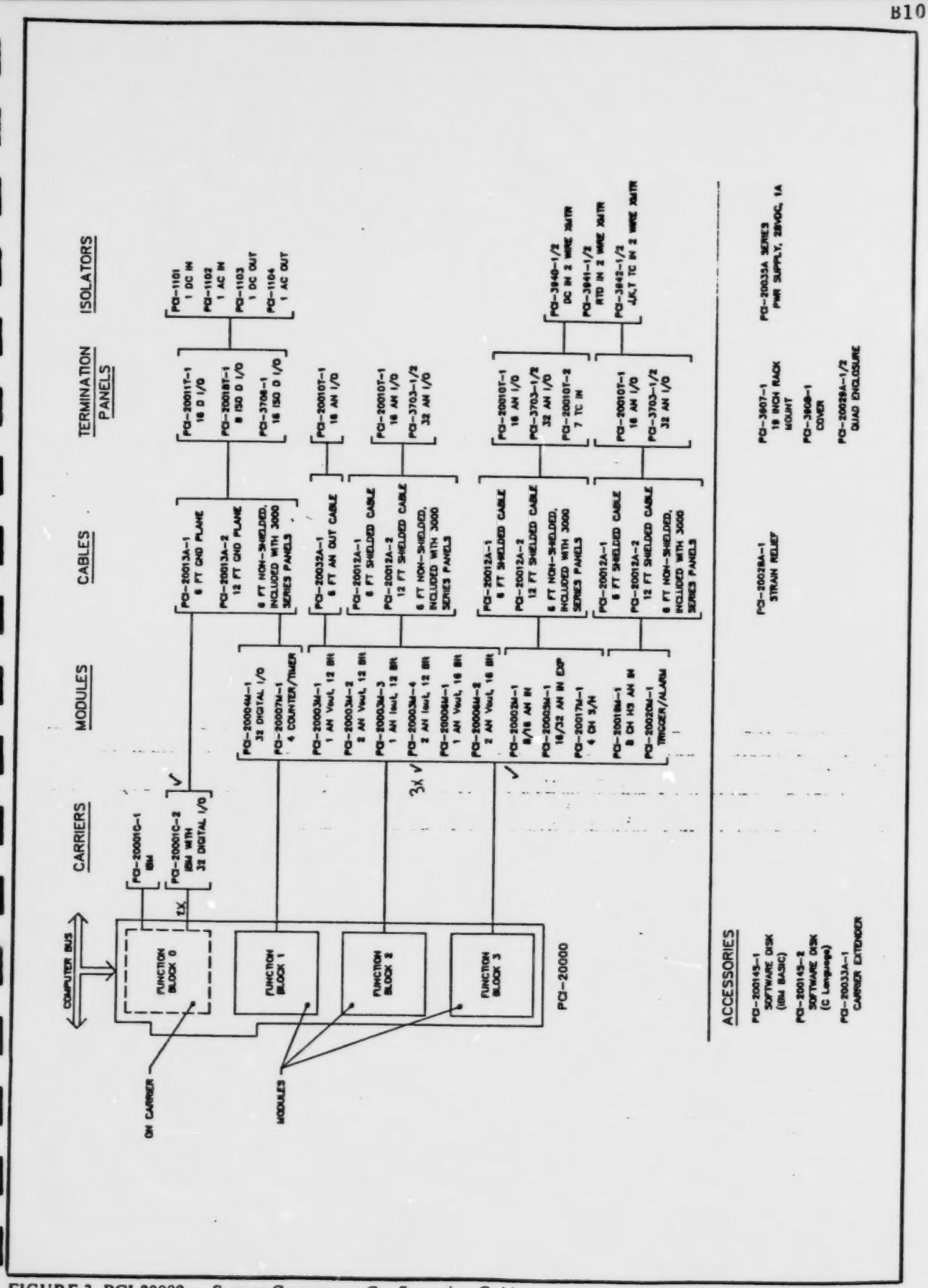

COMPUTER BUS
CARRIERS
MODULES
CABLES
TERMINATION PANELS
ISOLATORS
PCI-20000
FUNCTION BLOCK 0
FUNCTION BLOCK 1
FUNCTION BLOCK 2
FUNCTION BLOCK 3
PC-20001C-1 IBM
PC-20001C-2 IBM WITH 32 DIGITAL I/O
1X
3X
ON CARRIER
MODULES
PC-20004M-1 32 DIGITAL I/O
PC-20007M-1 4 COUNTER/TIMER
PC-20003M-1 1 AN Vout, 12 BIT
PC-20003M-2 2 AN Vout, 12 BIT
PC-20003M-3 1 AN Iout, 12 BIT
PC-20003M-4 2 AN Iout, 12 BIT
PC-20006M-1 1 AN Vout, 16 BIT
PC-20006M-2 2 AN Vout, 16 BIT
PC-20002M-1 8/16 AN IN
PC-20003M-1 16/32 AN IN EXP
PC-20017M-1 4 CH T/C
PC-20018M-1 8 CH HS AN IN
PC-20020M-1 TRIGGER/ALARM
PC-20013A-1 6 FT CND PLANE
PC-20013A-2 12 FT CND PLANE
6 FT NON-SHIELDED, INCLUDED WITH 3000 SERIES PANELS
PC-20032A-1 6 FT AN OUT CABLE
PC-20012A-1 6 FT SHIELDED CABLE
PC-20012A-2 12 FT SHIELDED CABLE
6 FT NON-SHIELDED, INCLUDED WITH 3000 SERIES PANELS
PC-20017-1 16 D I/O
PC-20018T-1 8 ISO D I/O
PC-3706-1 16 ISO D I/O
PC-20010T-1 16 AN I/O
PC-3703-1/2 32 AN I/O
PC-20010T-2 7 TC IN
PC-3940-1/2 DC IN 2 WIRE XMTR
PC-3941-1/2 RTD IN 2 WIRE XMTR
PC-3942-1/2 J,K,T TC IN 2 WIRE XMTR
PC-1101 1 DC IN
PC-1102 1 AC IN
PC-1103 1 DC OUT
PC-1104 1 AC OUT
PC-20028A-1 STRAIN RELIEF
ACCESSORIES
PC-3907-1 19 INCH RACK MOUNT
PC-3908-1 COVER
PC-20028A-1/2 QUAD ENCLOSURE
PC-20033A SERIES PWR SUPPLY, 28VDC, 1A
PC-20014S-1 SOFTWARE DISK (IBM BASIC)
PC-20015S-2 SOFTWARE DISK (C Language)
PC-20033A-1 CARRIER EXTENDER

FIGURE 3. PCI-20000 — System Component Configuration Guide.

FIGURE 2. PCI-20000 General System Specifications. Conditions: IBM PC, using most appropriate PCI-20000 hardware.

HOST COMPUTER COMPATIBILITY	Suitable for the IBM PC/XT/AT family of PC's, COMPAQ, AT&T or other hardware compatible personal computers.
MECHANICAL	Electrically, a CARRIER takes one expansion slot in the host. Mechanically, part or all of the adjacent slot may be occupied depending upon the installed module configuration. TERMINATION PANELS reside outside the host, optionally, in rack or table mount enclosures.
ANALOG INPUTS Single-ended or differential, voltage or current	±10mV to ±10V direct inputs (higher with attenuation on termination panel). 12-bit resolution, ±0.04% accuracy, ±0.04% linearity. PGA, G =1, 10, 100, 1000. CMV = ±10V. CMR = 106dB. Speed, up to 80K readings/sec. Up to 16 channels per module, and up to 80 channels per carrier using the 32-channel expansion modules.
ANALOG OUTPUTS	±10V and 4-20mA outputs. 12-bit resolution, ±1/2LSB linearity, monotonic, 8V/μsec slew rate. ±10 V output, 16-bit resolution, ±0.003% FSR linearity. 1 or 2 channels per module, up to 6 channels per carrier.
DIGITAL Input & Output	TTL compatible, 24mA current sink, 15mA current source. Read/set bits, bytes or words. High voltage isolation (4000V AC/DC) and 3A (AC/DC) switch capability using the opto-isolation termination panels. 32 points per module, up to 128 points per carrier.
COUNTERS	TTL compatible. Up to 8MHz inputs. Count events, accumulate, measure frequency. 16-bit resolution. 8MHz time-base with 0.008% accuracy. 4 counters per module, up to 12 counters per carrier.
PULSE OUTPUTS	TTL compatible. Finite or continuous outputs. Pulse or squarewave outputs. Output frequencies of .002Hz to 2MHz. 125ns resolution. .008% accuracy.
TERMINATION PANELS	Provides a screw terminal interface between the system and field signals. Types available: Analog I/O, Thermocouple Input, Digital I/O and Opto-isolation. Rack and table top enclosures for 1 to 4 panels are available.
TEMPERATURE RANGE	0 to 50°C, Ambient.
POWER REQUIREMENTS	+5V @ 600mA Quiescent carrier (1C-2) current, add individual modules POWER for total. 2.9A Max current, fully loaded. DC to DC converter efficiency = 50%.
SOFTWARE	Applications software packages provide machine language routines that can be called from high level languages to control most functions. Complete programs for instrumentation and control functions are also available.

SPEED SUMMARY

All data is expressed in readings/sec, and includes the time to read or write to RAM.

PARAMETER	CONDITIONS	IBM-PC	IBM-AT
ANALOG INPUT	PCI-20014S-1 Software		
	Normal Analog Read mode	130	337
	Thermocouple Read mode	75	234
	Block mode, 2M Module	7K	10K
	19M Module	45K	65K
ANALOG OUTPUT	PCI-20014S-1 Software	129	338
DIGITAL I/O	PCI-20014S-1 Software	126	326
	Assembly code, with sync	45K	90K
COUNTER	PCI-20014S-1 Software	126	331
	Assembly code, sync and reset	24K	48K

CONFIGURING A PCI-20000 SYSTEM

This section is an aid in configuring a system for a given application. The first step involves listing the specific input/output requirements for each application. With this information, the following guide will provide the needed PCI-20000 system specifications.

The PCI-20000 is intended for small and medium sized tasks, where the host computer can be located near the application. The maximum channel capacity for this system is shown in Figure 2. Note that more than one carrier can often be used to increase the system's capacity. Carriers can either be installed within the host computer or in expansion enclosures. More detailed information about each component appears in later sections of this brochure.

For large scale, distributed or remote applications, the PCI-3000 system is suggested. This type of system can be expanded to almost 32000 channels and can be located at any distance from the host computer. Please refer to the Burr-Brown product data book or contact your local representative for the appropriate PCI-3000 literature.

Fundamental to configuring a system is the selection of a carrier. The difference between the two available carriers is the inclusion of 32 digital I/O points on the PCI-20001C-2. This carrier provides a significant level of digital capability, at very low cost, without occupying an instrument module location.

Figure 3 graphically shows all of the components that comprise the PCI-20000 system. Also indicated are the associated options and accessories. Compatibility of each group of components is indicated by the interconnecting lines. Note that there are compatible components having part numbers in the 1100, 3000 and 20000 series.

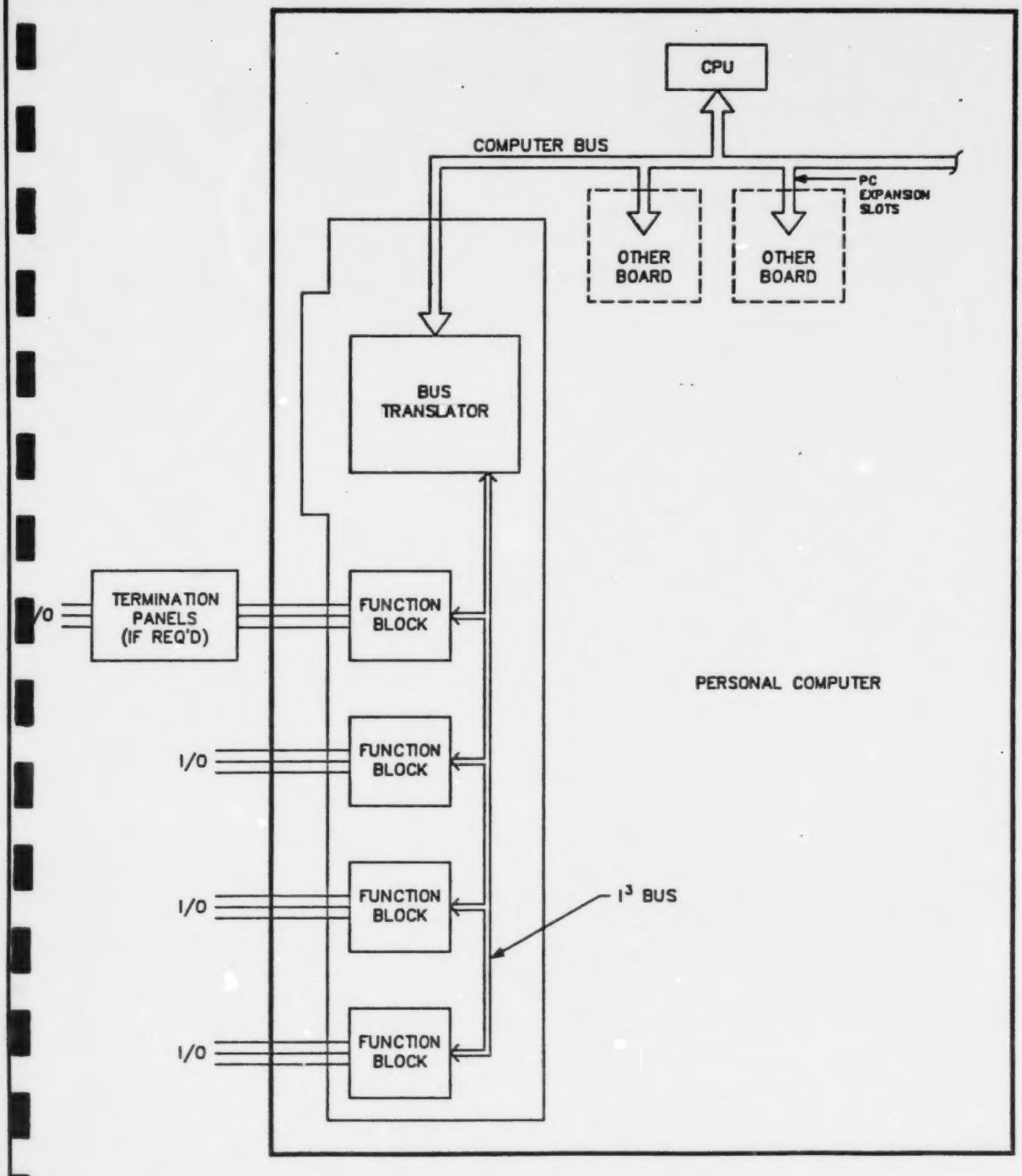
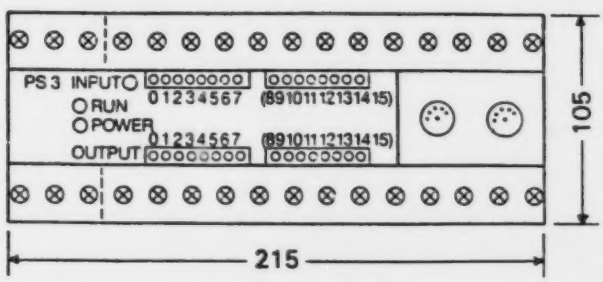


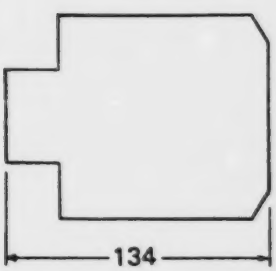
FIGURE 1. Personal Computer-Based Data Acquisition and Control System - Block Diagram.

Technical Data

	PS 3-AC	PS 3-8	PS 3-DC
Power supply	110/120 VAC 50-60Hz 220/240 VAC 50-60Hz	110/120 VAC 50-60Hz 220/240 VAC 50-60Hz	24 V DC 24 V DC
Inputs			
Digital + 24V (opto-coupled active H technology)	16	8	16
Analog 0... 10 V DC	4	—	4
High-speed counter input 10 kHz	1	—	1
Outputs			
Transistor + 24V 0.5A	—	—	16
Relay 0... 240 V AC, 2A (24VDC, 0.5A)	8	8	—
Analog 0... 10 V DC	1	—	1
User program memory	1k instructions	1k instructions	1k instructions
Internal relays (markers)	576	576	576
Latching relays (retentive markers)	64	64	64
Program modules			
Timers, counters	32 each	32 each	32 each
Comparators, shift registers	32 each	32 each	32 each
Clock modules	32	—	32
Real-time clock with calendar	1	—	1
Arithmetic functions (+, −, ×, ÷)	yes	yes	yes
Bit, byte, and word markers	yes	yes	yes
Cycle time for 1K addresses	typically < 5 ms	typically < 5 ms	typically < 5 ms
Status indication	LED	LED	LED
Drop-out delay	5 ms	5 ms	5 ms
Isolated contacts	yes	yes	no
Operating temperature	0-55°C	0-55°C	0-55°C
Weight	3 kg	3 kg	2 kg

PS 3 Dimensions





PS3

Klockner-Moeller has developed a compact, rugged low cost, programmable controller PS 3.

Bearing in mind the variety of functions required of modern control systems, the highly efficient PS 3 has a unit extension facility. Its analog input/output capability makes it ideal for closed loop controls — previously the exclusive domain of larger programmable controllers — and permit its use as a decentralized unit for the PS 32. This, coupled with the comprehensive software library which the microprocessor, offers, makes the PS 3 eminently suitable for machine controls of low to medium complexity.

Its high speed input (10 kHz) and powerful arithmetic function +, −, ×, ÷, embodies the complete solution for high speed counting.

Communication with a hierarchical computer/programmer is an essential requirement of any PC system. Having two RS 485 interface ports, the PS 3 can be programmed via a hand held programmer (PRG 3), a light-pen programmer (using the PRG 300) or with any IBM-PC or compatible unit.

Features

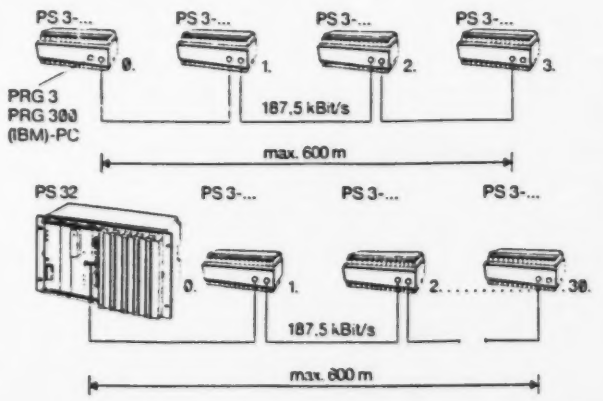
- Real-time clock
  Up to 32 preselectable timed events
  3 decision parameters for testing conditions:
  LT - less than present time
  EQ - at present time
  GT - greater than present time
  Applications: Traffic light controls, energy management systems, and other timed related control.

- Arithmetic functions:
  Four functions:
  ADD - Addition
  SUB - Subtraction
  MUL - Multiply
  DIV - Division
  Negate functions
  Applications: Batch processes requiring some formulations, data handling, etc.

- Analog inputs and outputs
  Quantity -4 inputs per unit (PS 3-AC or PS3-DC)
  0-10V or 4-20mA (using loading resistor)
  Quantity - 1 output per unit (PS3-AC or PS3-DC)
  0-10V/1mA
  Maximum cable length - 10 m screened
  Applications: Control and monitoring of process variables, etc.

- High-speed input (10 kHz)
  Quantity -1 per unit (PS3-AC or PS3-DC) 10 kHz, 24V DC, 10mA. 20-30 V
  Maximum cable length - 10 m screened.
  Applications: High-speed machinery control

- 32 timers 0.1 to 6553.5 seconds
- 32 counters Up and down
- 32 shift registers Forward and reverse 16 step
- 32 comparators for values from 0 to 65,535
- 576 internal relays (Markers)
- 64 latching relays (Retentive markers)
- 1 one second pulsing marker
- 1 real-time clock (PS 3-AC or PS 3-DC)
- DIN rail mounting
- Connection to heirarchical programmable controller/computer
- Hand-held programmer
- Light-pen programmer
- IBM-PC compatible programming software
- RS 485 noise immune interface.
- Expandable



APPENDIX C

ATLANTIC WIND TEST SITE
WIND/DIESEL CONNECTION DIAGRAMS

ATLANTIC WIND TEST SITE

WIND / DIESEL

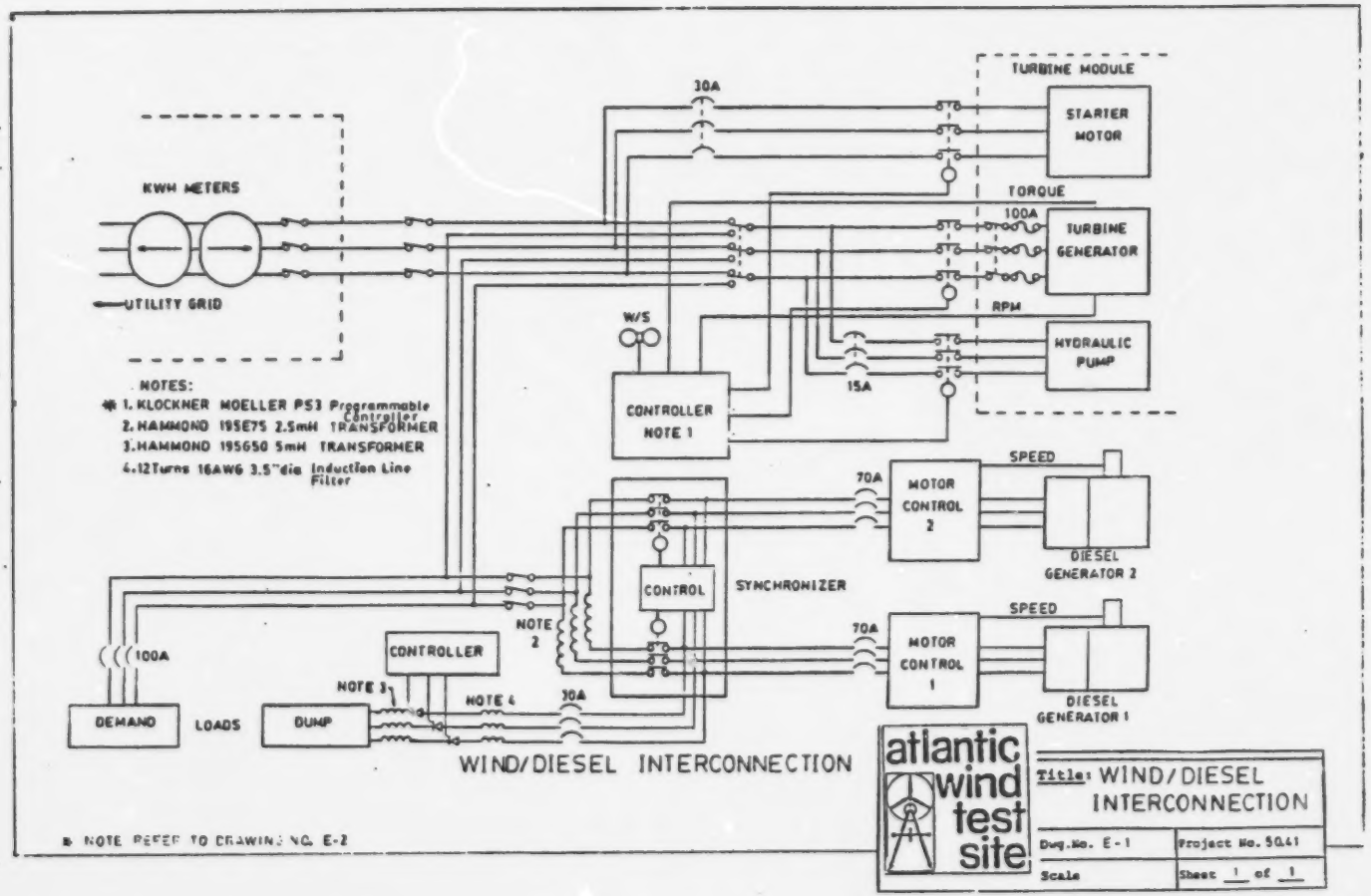
Project No.50.41

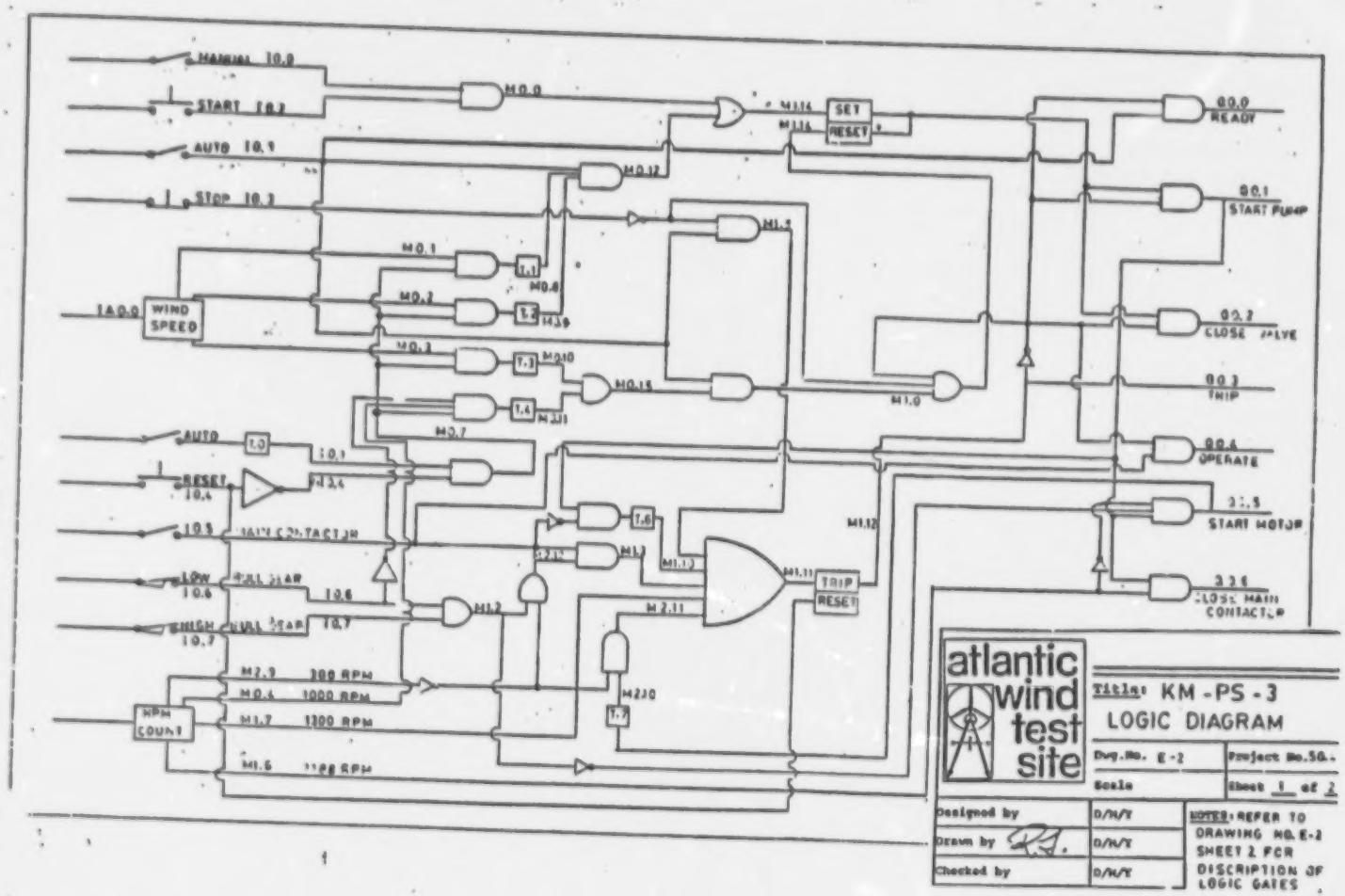
DRAWING

E-1 INTERCONNECTION
E-2 KM-PS3 LOGIC DIAGRAM
E-2 FIRST OUT ANNUNCATORS
E-3 WIRING DIAGRAM of KM-PS 3
E-4 WIRING DIAGRAM of DOOR PANEL
E-5 TERMINATION DIAGRAM

S-1 W/D PLANT ARRAGEMENT
S-2 VAWT and DIESEL LAYOUT
S-3 W/D GENERAL LAYOUT
S-4 CABLE IDENTIFICATION
S-5 INSTRUMENTATION/CONTOL ARRANGEMENT

F-3 MODULE FOUNDATION
F-4 DIESEL FOUNDATION


TURBINE MODULE
30A
STARTER MOTOR
KWH METERS
TORQUE
100A
TURBINE GENERATOR
UTILITY GRID
W/S
RPM
HYDRAULIC PUMP
15A
NOTES:
1. KLOCKNER MOELLER PS3 Programmable Controller
2. HAMMOND 195E75 2.5mH TRANSFORMER
3. HAMMOND 195G50 5mH TRANSFORMER
4. 12Turns 16AWG 3.5"dia Induction Line Filter
CONTROLLER NOTE 1
SPEED
70A
MOTOR CONTROL 2
DIESEL GENERATOR 2
CONTROL
SYNCHRONIZER
NOTE 2
CONTROLLER
100A
NOTE 3
NOTE 4
30A
70A
MOTOR CONTROL 1
SPEED
DIESEL GENERATOR 1
DEMAND
LOADS
DUMP
WIND/DIESEL INTERCONNECTION
atlantic wind test site
Title: WIND/DIESEL INTERCONNECTION
Dwg.No. E-1
Project No. 5041
Scale
Sheet 1 of 1
* NOTE REFER TO DRAWING NO. E-2

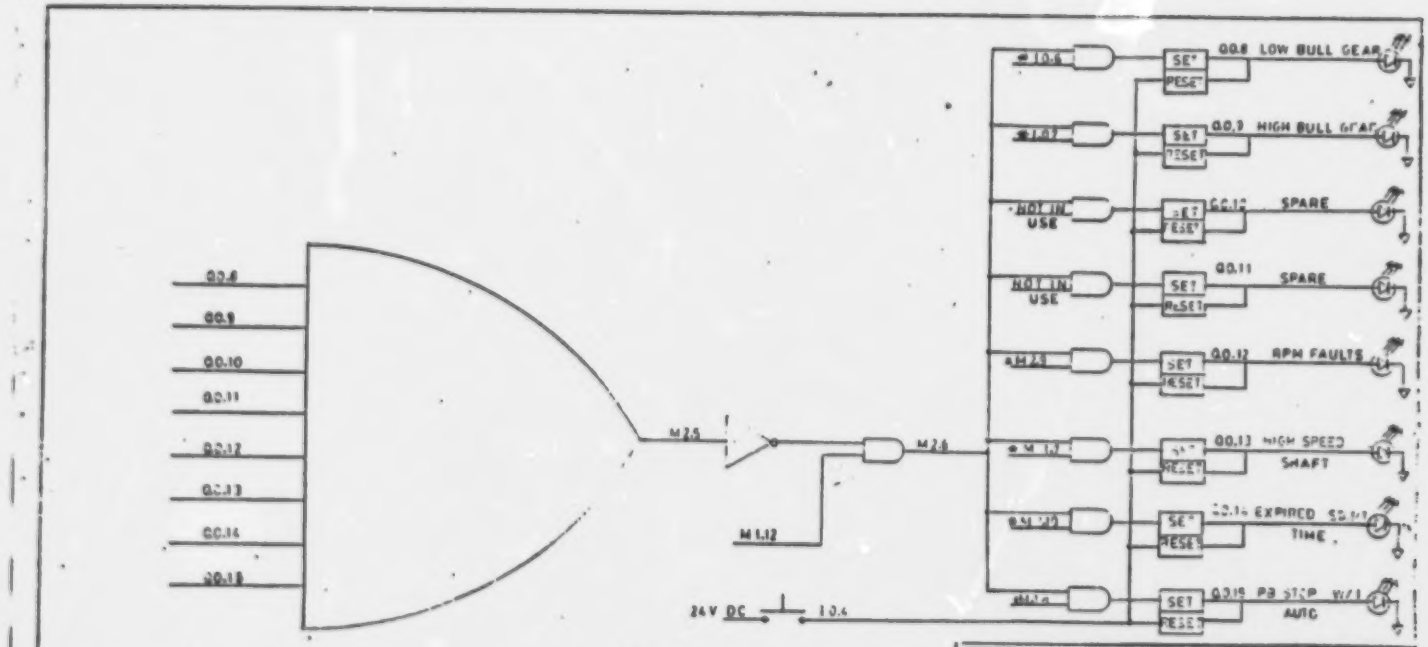


atlantic wind test site

Title: KM-PS-3
LOGIC DIAGRAM

Dwg.No. E-2	Project No.50-
Scale	Sheet 1 of 2

Designed by	D/M/Y	NOTES: REFER TO DRAWING NO. E-2 SHEET 2 FOR DISCRIPTION OF LOGIC GATES
Drawn by	D/M/Y	
Checked by	D/M/Y	



* REFER TO DRAWING NO. E-2 SHEET 1

atlantic wind test site

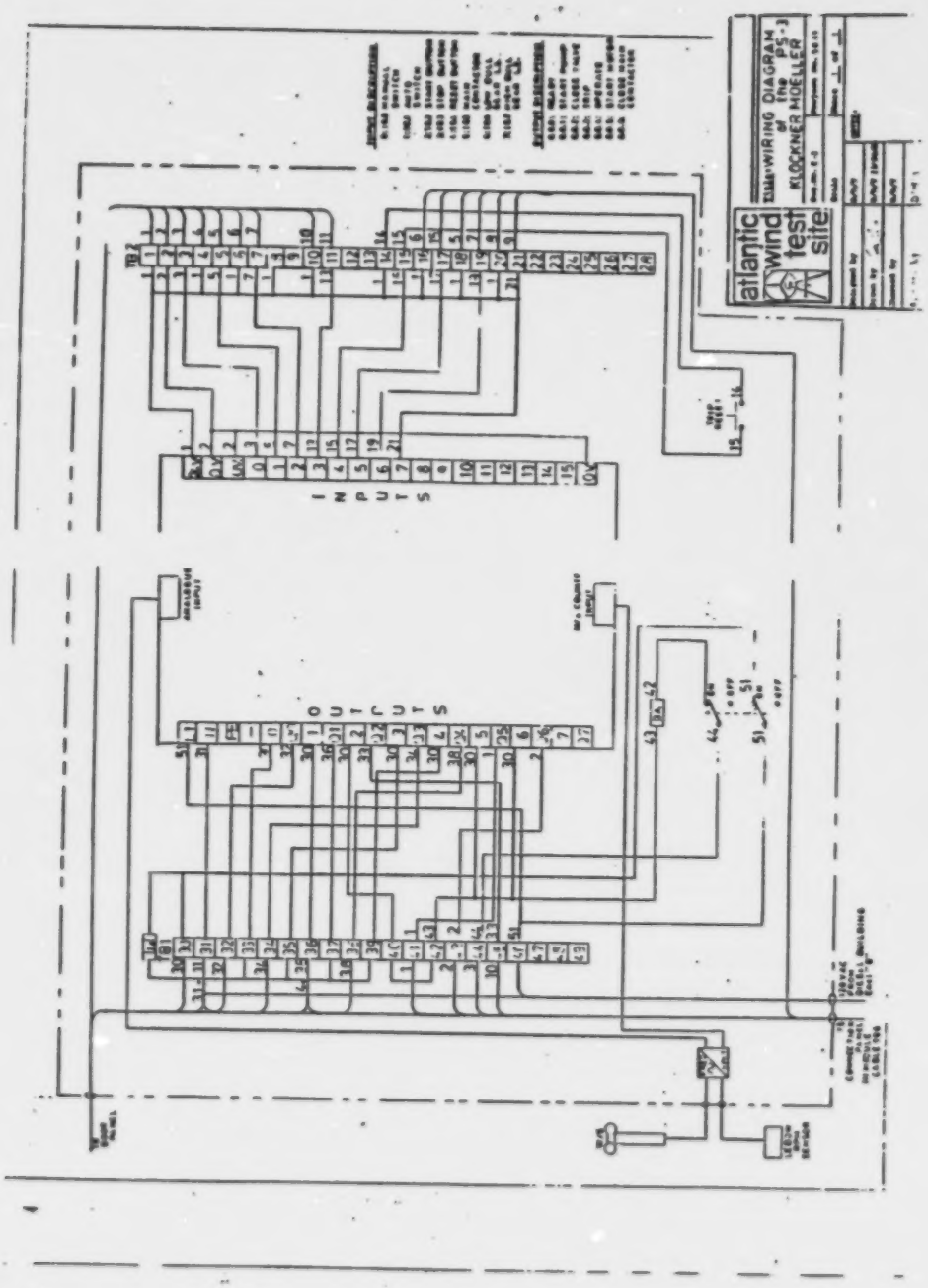
Title: FIRST OUT ANNUNCATORS LOGIC DIAGRAM

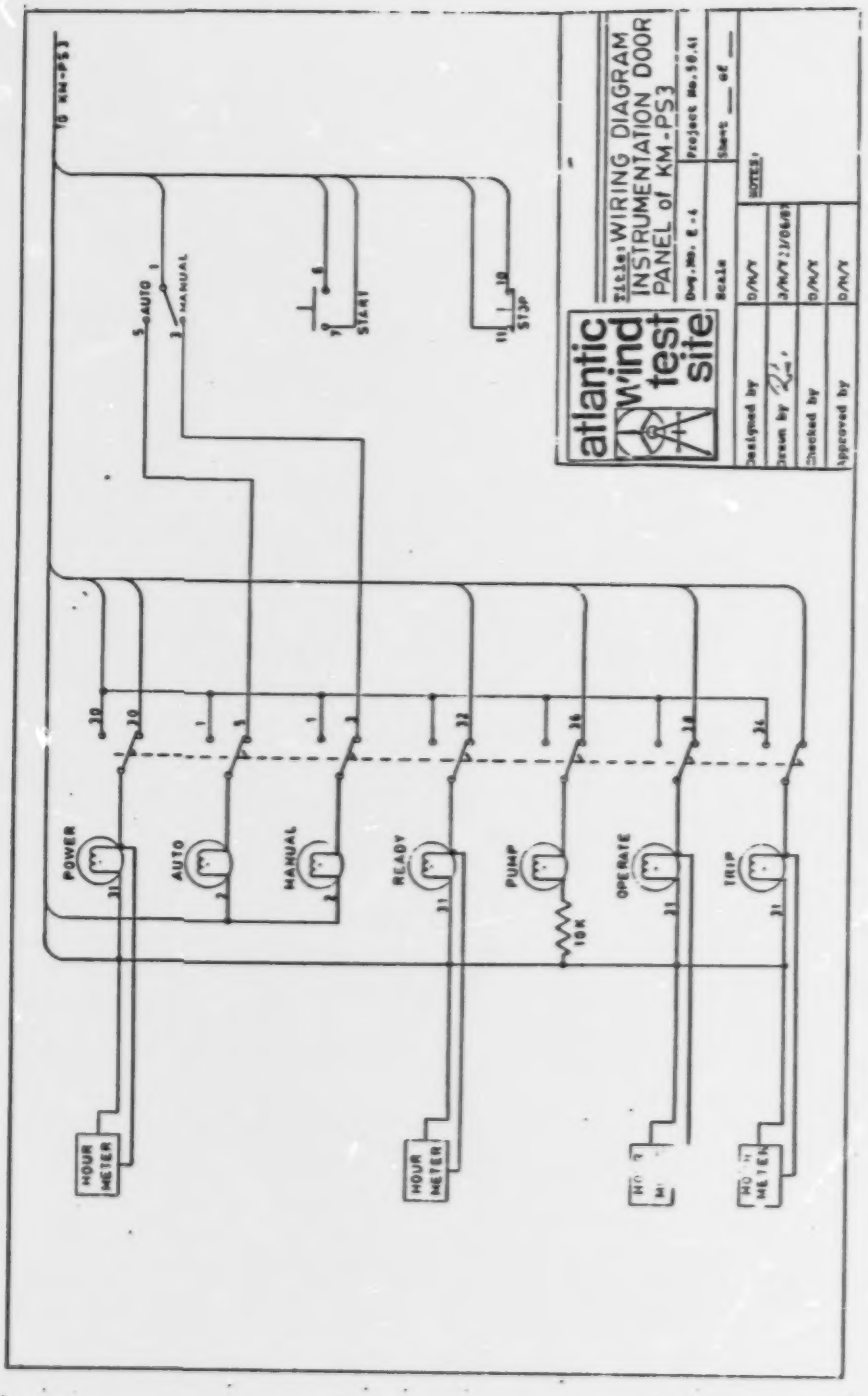
Dwg. No. E-2 | Project No. 80.41

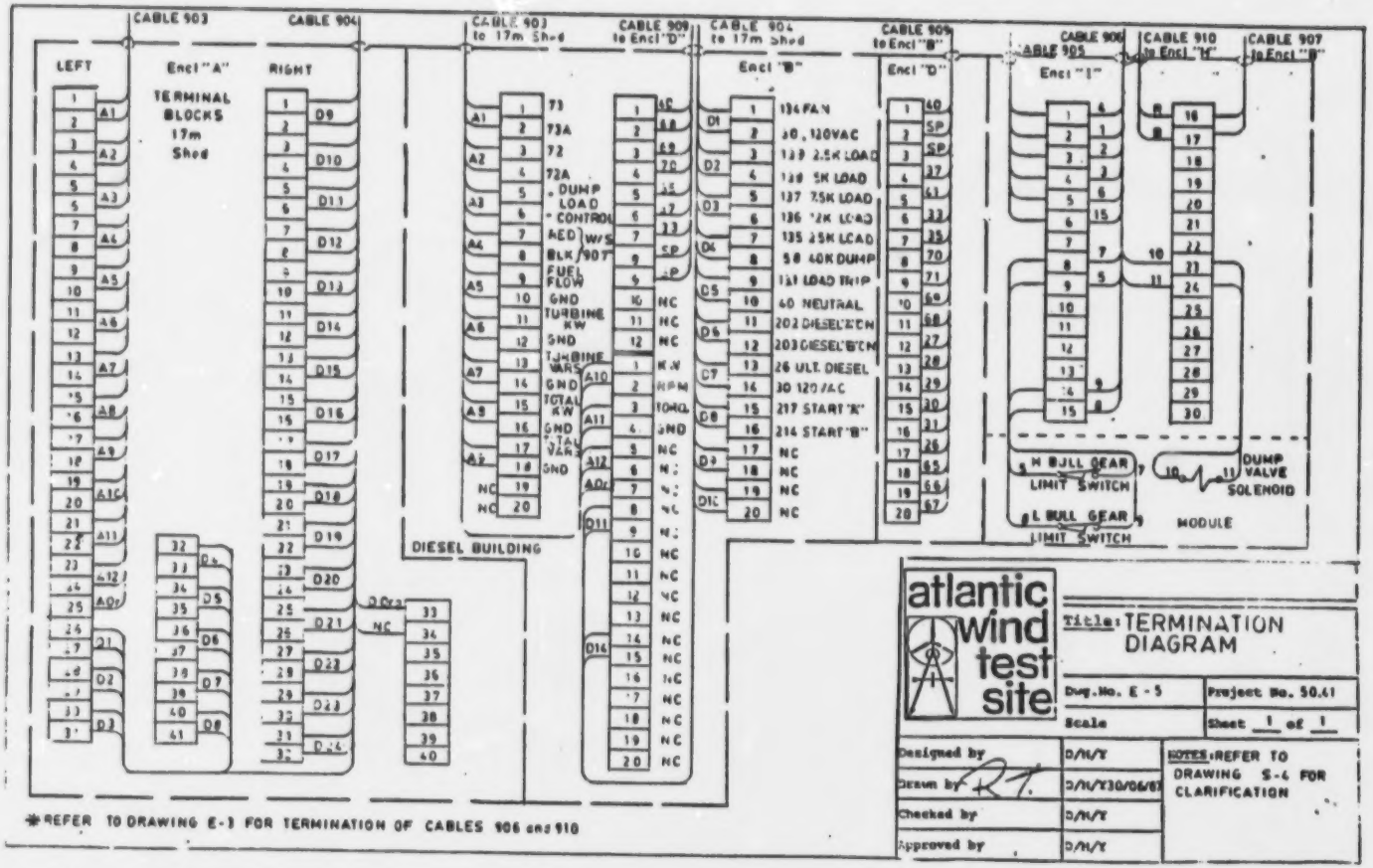
Scale | Sheet 2 of 2

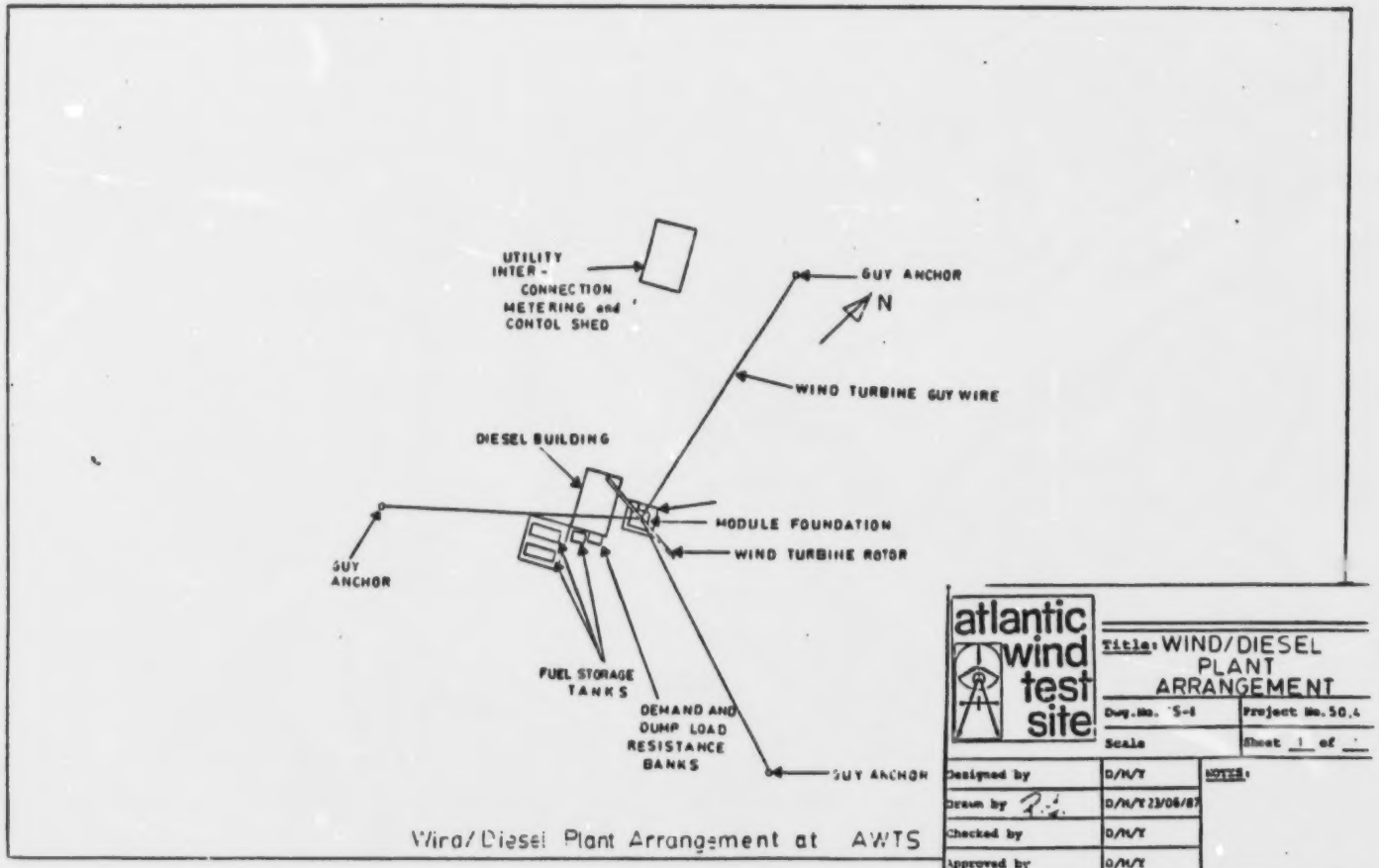
Designed by | D/M/Y | NOTES:

Drawn by | D/M/Y

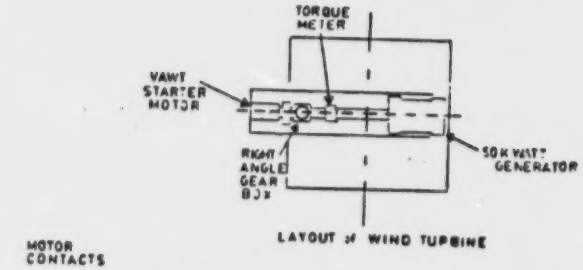

WIRING DIAGRAM
OF
THE "PS-3"
KLOCKNER MOELLER
atlantic
wind
test
site


16 KM-PS3
AUTO
MANUAL
START
STOP
POWER
AUTO
MANUAL
READY
PUMP
10Ω
OPERATE
TRIP
HOUR METER
atlantic wind test site
TITLE: WIRING DIAGRAM INSTRUMENTATION DOOR PANEL of KM-PS3
Designed by D/M/Y
Drawn by D/M/Y
Checked by D/M/Y
Approved by D/M/Y
NOTES:

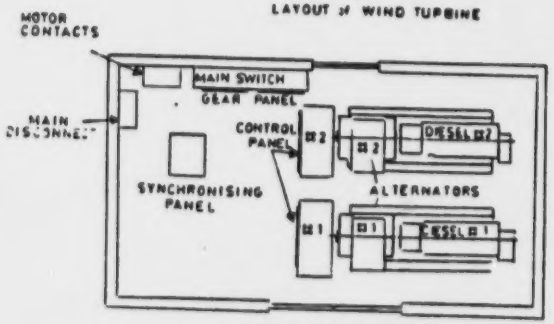

CABLE 903
CABLE 904
CABLE 903 to 17m Shed
CABLE 909 to Encl "D"
CABLE 904 to 17m Shed
CABLE 909 to Encl "B"
CABLE 906
CABLE 905
CABLE 910 to Encl "H"
CABLE 907 to Encl "B"
LEFT
Encl "A"
TERMINAL BLOCKS 17m Shed
RIGHT
Encl "B"
Encl "D"
Encl "I"
DIESEL BUILDING
H BULL GEAR LIMIT SWITCH
L BULL GEAR LIMIT SWITCH
DUMP VALVE SOLENOID
MODULE
* REFER TO DRAWING E-3 FOR TERMINATION OF CABLES 906 and 910
atlantic wind test site
Title: TERMINATION DIAGRAM
Dwg. No. E - 5
Project No. 50.41
Scale
Sheet 1 of 1
Designed by
Drawn by
Checked by
Approved by
NOTES: REFER TO DRAWING S-4 FOR CLARIFICATION



Wind/Diesel Plant Arrangement at AWTS



LAYOUT of WIND TURBINE

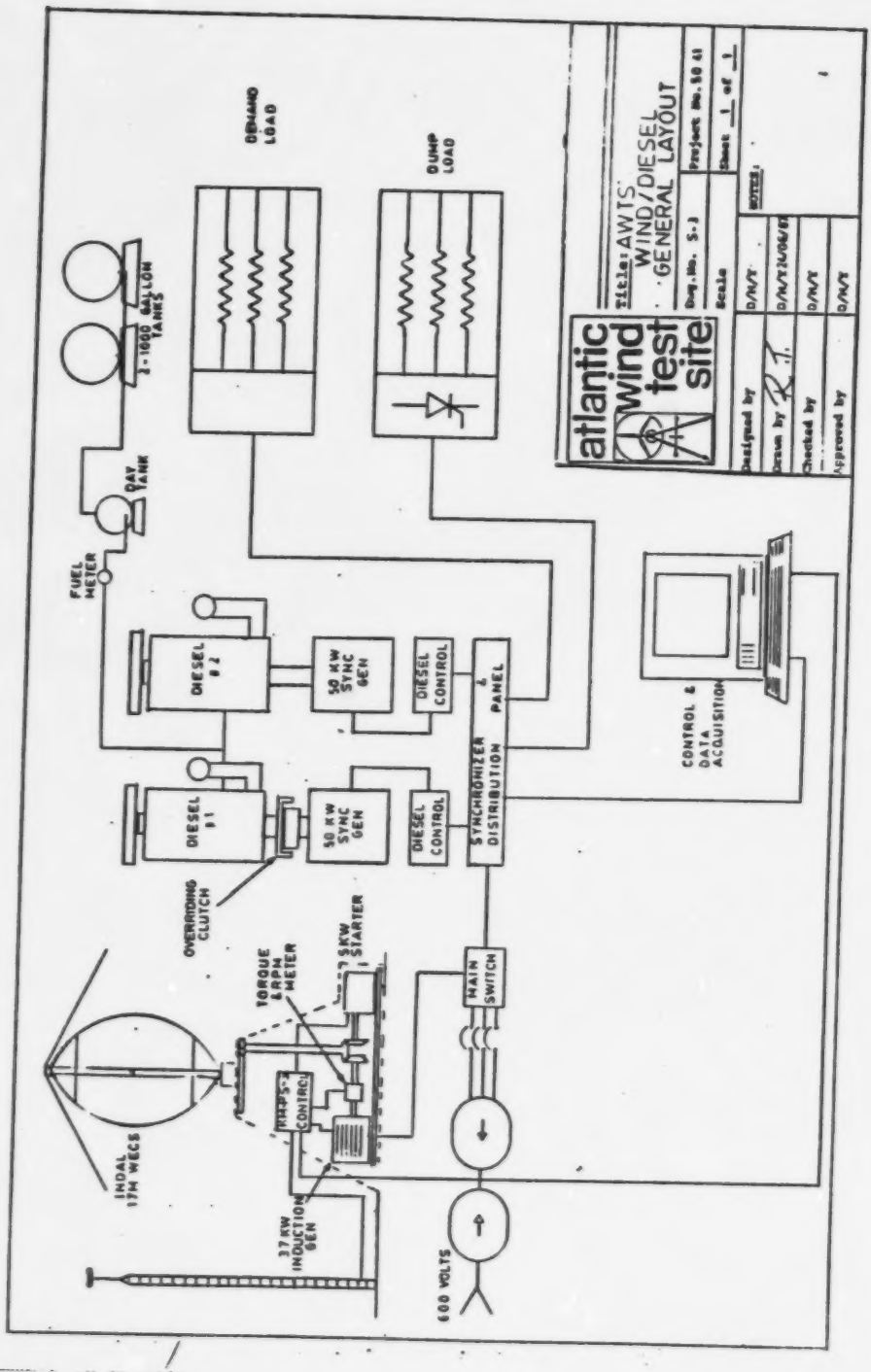


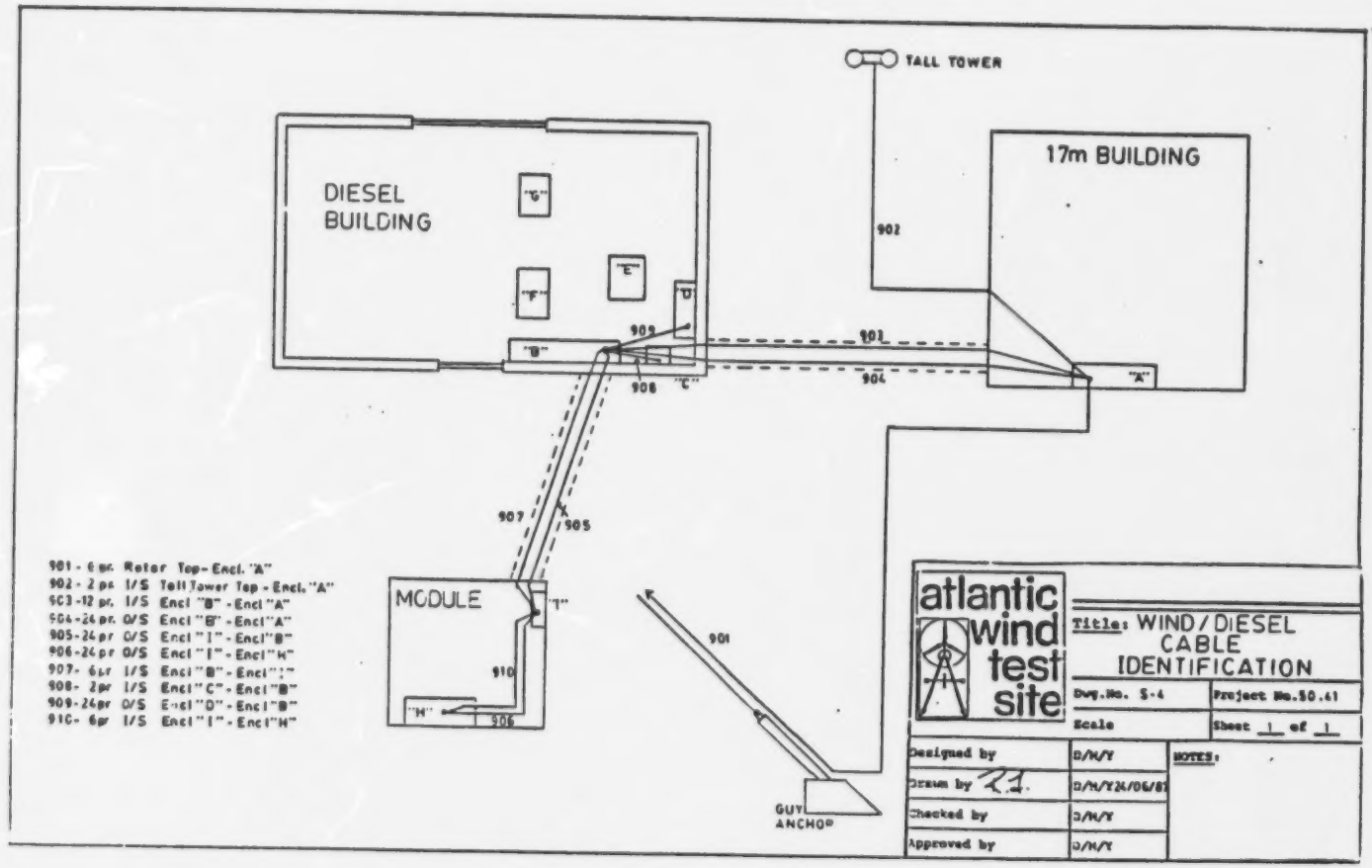
LAYOUT of DIESEL SYSTEM

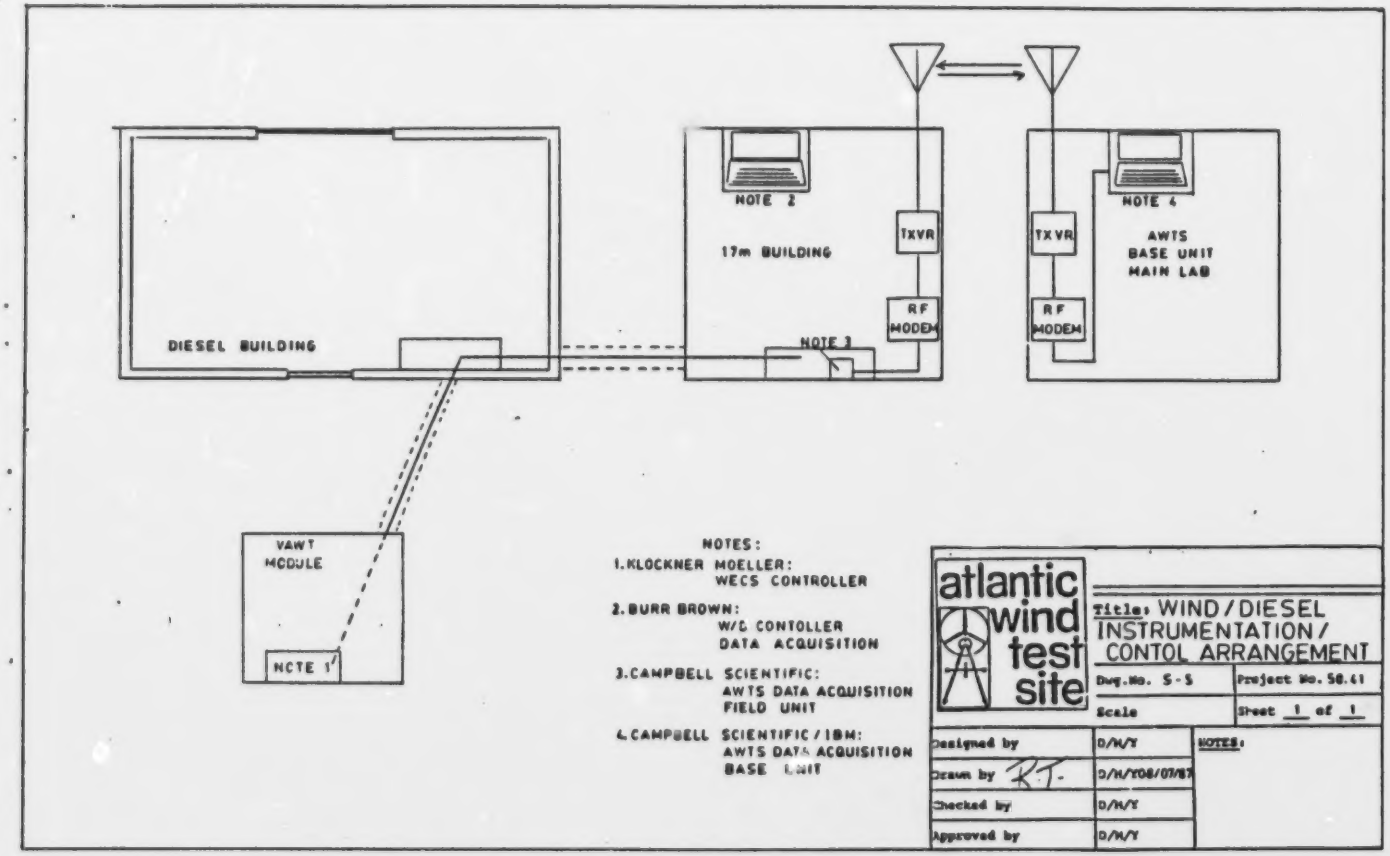
atlantic wind test site

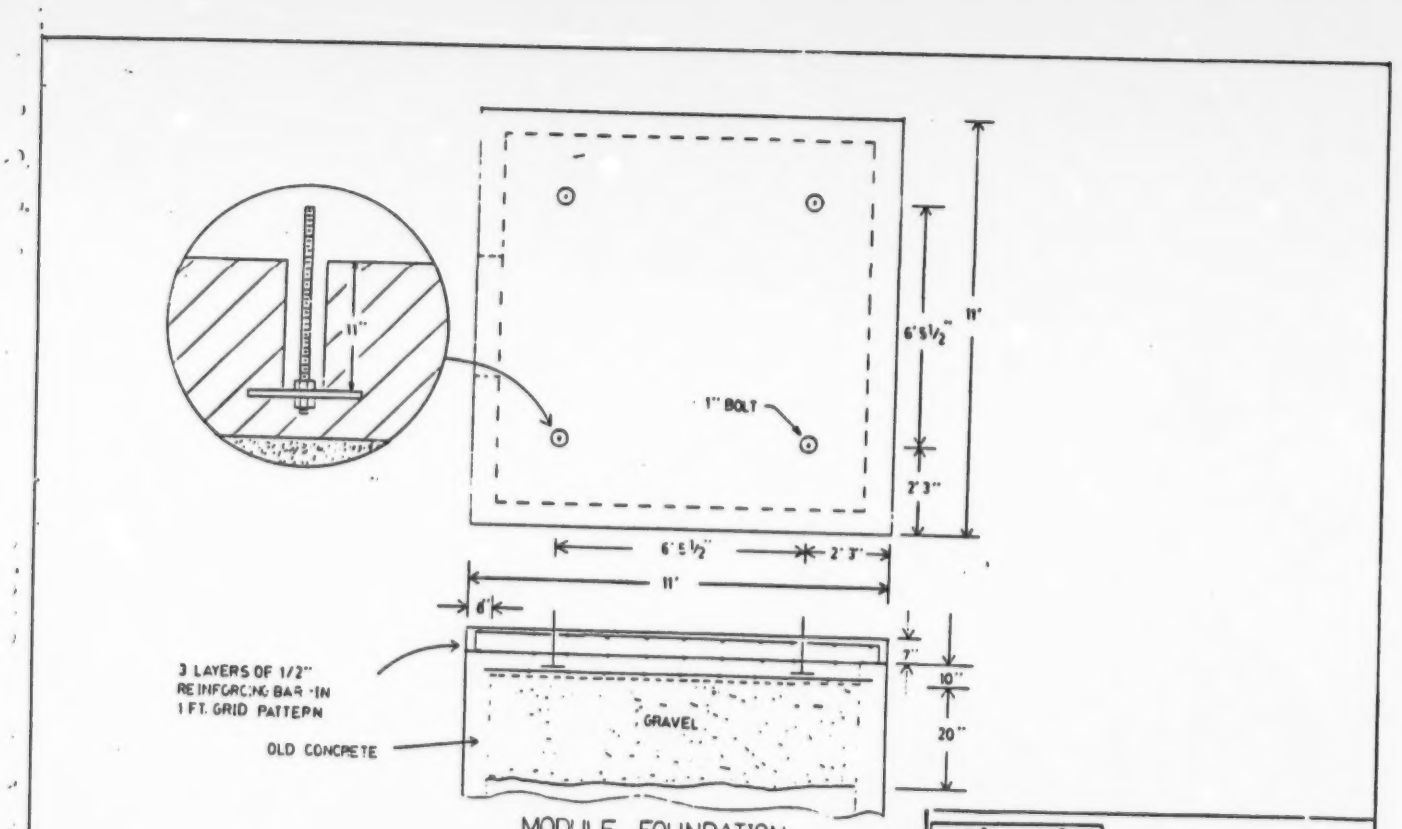
Title: VAWT and DIESEL LAYOUT

Dwg. No. S-2		Project No. 80.4
Scale		Sheet 1 of 1
Designed by	D/M/Y	NOTES:
Drawn by RJ	D/M/Y 27/06/80	
Checked by	D/M/Y	
Approved by	D/M/Y	


atlantic wind test site
Title: AWTS WIND/DIESEL GENERAL LAYOUT
Dwg. No. S-1
Project No. 80 41
Scale
Sheet 1 of 1
NOTES:
Designed by D/N/T
Drawn by D/N/T
Checked by D/N/T
Approved by D/N/T
DEMAND LOAD
DUMP LOAD
2 - 1000 GALLON TANKS
DAY TANK
FUEL METER
DIESEL #2
50 KW SYNC GEN
DIESEL CONTROL
SYNCHRONIZER DISTRIBUTION PANEL
CONTROL & DATA ACQUISITION
DIESEL #1
50 KW SYNC GEN
DIESEL CONTROL
OVERRIDING CLUTCH
TORQUE & RPM METER
75 KW STARTER
MAIN SWITCH
INDAL 17M WECS
MKP 5-2 CONTROL
37 KW INDUCTION GEN
600 VOLTS


TALL TOWER
17m BUILDING
DIESEL BUILDING
"G"
"F"
"E"
"D"
"B"
"C"
"A"
902
903
904
908
MODULE
"I"
"H"
910
906
907
905
901
GUY ANCHOR
901 - 6 pr. Rotor Top - Encl. "A"
902 - 2 pr. I/S Tall Tower Top - Encl. "A"
903 - 12 pr. I/S Encl "B" - Encl "A"
904 - 24 pr. O/S Encl "B" - Encl "A"
905 - 24 pr O/S Encl "I" - Encl "B"
906 - 24 pr O/S Encl "I" - Encl "H"
907 - 6 pr I/S Encl "B" - Encl "I"
908 - 2 pr I/S Encl "C" - Encl "B"
909 - 24 pr O/S Encl "D" - Encl "B"
910 - 6 pr I/S Encl "I" - Encl "H"
atlantic wind test site
Title: WIND / DIESEL CABLE IDENTIFICATION
Dwg. No. S-4
Project No. 80.41
Scale
Sheet 1 of 1
Designed by D/M/Y
Drawn by D/M/Y
Checked by D/M/Y
Approved by D/M/Y
NOTES:


DIESEL BUILDING
VAWT MODULE
NOTE 1
NOTE 2
17m BUILDING
TXVR
RF MODEM
NOTE 3
TXVR
RF MODEM
NOTE 4
AWTS BASE UNIT MAIN LAB
NOTES:
1. KLOCKNER MOELLER: WECS CONTROLLER
2. BURR BROWN: W/G CONTOLLER DATA ACQUISITION
3. CAMPBELL SCIENTIFIC: AWTS DATA ACQUISITION FIELD UNIT
4. CAMPBELL SCIENTIFIC / IBM: AWTS DATA ACQUISITION BASE UNIT
atlantic wind test site
Title: WIND / DIESEL INSTRUMENTATION / CONTOL ARRANGEMENT
Dwg. No. S-5
Project No. 58.41
Scale
Sheet 1 of 1
Designed by D/M/Y
Drawn by R.T. D/M/Y08/07/87
Checked by D/M/Y
Approved by D/M/Y
NOTES:



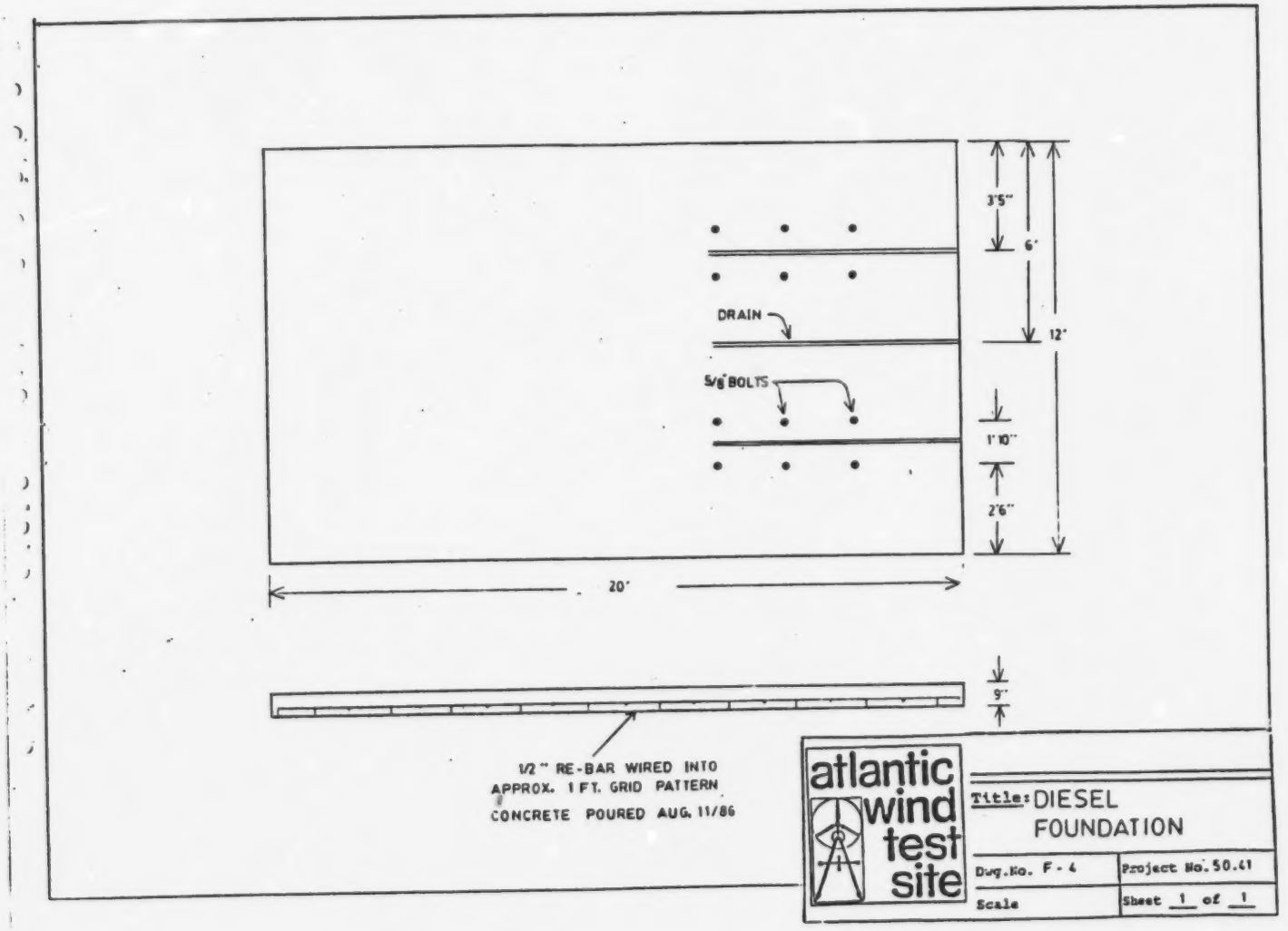
MODULE FOUNDATION
17m VAWT

atlantic wind test site

Title: MODULE FOUNDATION 17m VAWT

Dwg.No. F-3 | Project No

Scale | Sheet 1 of 1


3'5"
6"
12"
DRAIN
5/8" BOLTS
1'10"
2'6"
20'
9"
1/2" RE-BAR WIRED INTO
APPROX. 1 FT. GRID PATTERN
CONCRETE POURED AUG. 11/86
atlantic wind test site
Title: DIESEL FOUNDATION
Dwg.No. F - 4
Project No. 50.41
Scale
Sheet 1 of 1

APPENDIX D

AWTS WIND/DIESEL SYSTEM
WIND TURBINE CONTROL SYSTEM

AWTS WIND/DIESEL SYSTEM

"WIND TURBINE CONTROL SYSTEM"

INTRODUCTION

The accurate, reliable, and safe control of operating wind turbines is essential whether in grid connected or autonomous operation.

Typically, control systems for the various wind turbines on the market have been developed by the manufacturers themselves or by companies specializing in designing custom control systems. This technique often results in a system that is rather inflexible, quite expensive or both.

In recent years, with developments in the electronics industry, costs, availability and performance of programmable logic controllers have improved greatly. This means that the wind industry can utilize high volume, low priced control systems that are very flexible and powerful.

The Klockner Moeller PS3 is a small programmable logic controller selected for this application. Figure 1 and 2 describe the unit which has the capability of monitoring 16 digital inputs and four analog inputs (eight bit resolution) as well as a high speed counter (10 khz). It will drive eight digital outputs (2 amps) and one analog output. The unit can be programmed to accept up to 1000 instructions, which can utilize a total of 576 internal markers, 32 timers, 32 counters, and 32 comparators. Cycle time is 5 milliseconds per 1000 instructions. Up to 1K of user memory is available for instructions and this memory is protected from power failure by two 1.5V batteries. Cycle time is <5ms/1K instruction. There is also a simulator board with which you can simulate inputs to confirm function. Table 1 lists the program instructions.

AWTS APPLICATION OF PS3

The PS3 is being used to control the operation of a grid connected vertical axis wind turbine (VAWT).

The inputs are:

I0.0 Manual Switch

I0.1 Auto Switch

I0.2 Start P.B.

I0.3 Stop P.B.

I0.4 reset P.B.

I0.5 Main contactor

I0.6 Low bull gear limit switch

I0.7 high bull gear limit switch

The high speed counter is used to monitor rpm and one of the analog inputs monitors an anemometer.

The outputs are:

Q0.0 Unit ready

Q0.1 Start hydraulic pump

Q0.2 Close dump solenoid valve

Q0.3 Unit tripped

Q0.4 unit operating

Q0.5 Start starter motor

Q0.6 Close main contactor

There is also eight LEDS that are being used to annunciate first out trip conditions for easy indication of problem area. These conditions are:

Q0.8 Low bull gear

Q0.9 High bull gear

Q0.10 Low lube flow

Q0.11 Vibration

Q0.12 RPM Problem

Q0.13 High speed shaft overspeed

Q0.14 Expired start time

Q0.15 stop push button while in auto

As indicated in Logic diagram (fig 3 & 4) a start may be initiated in either manual or automatic mode. In automatic mode, a start is initiated when wind speeds are determined to be between cutin and cutout valves for a preset period of time. If an auto start initiated and there is no trip condition the hydraulic pump will start and the electric dump valve will close. Once the bull gear is raised from the brake pads the low bull gear limit switch will open and the starter motor will be energized. The motor will remain energized until the shaft speed reaches 900 RPM at which point the motor comes off line. The wind turbine will continue to accelerate if there is adequate wind. Once the turbine reaches 1190 RPM the main contactor will close. If the wind speed drops and the rpm drops below 1190 for a period of time the main contactor will open leaving the turbine in a coast mode until the winds pick up again. If the winds drop to where the shaft speed is less than 1000 rpm the machine is shut down until the winds are again strong enough to operate.

If unit is operating in automatic mode and wind speed is above 20m/sec for one minute a high wind speed shut down is initiated and unit waits until wind speed drops to an acceptable level before starting.

The unit may be started at any time in the manual mode. In this mode, it must be shut down manually unless a trip condition occurs. A trip condition in either automatic or manual mode will cause the unit to be shut down until the trip is acknowledged. Trips are initiated in the following instances:

1. Generator shaft speed greater than 1300 rpm.

2. Hydraulic pump on for three minutes without the main contactor energizing.

3. Main contactor is energized and there is a bull gear low or bull gear high or rpm is below 300.

4. Starter motor on and the generator speed is less than 300 rpm within 20 seconds.

5. Manual stop initiated while in automatic.

The program as tested in table 1 allows the turbine to be operated in a safe reliable manner over the entire range of operational wind speeds. It enables automatic starting and stopping of the wind turbine as wind conditions vary. In the event some unsafe condition develops it will automatically shut the unit down until the problem is rectified with the hardware used. It is also flexible enough to simply change any of the operational parameters so desired.

AWTS - PROGRAM SEQUENCE

Following is a listing of program steps to enable the KM-PS3 to automatically control the operation of a grid connected wind turbine over a range of all wind speeds in a safe and reliable manner.

```
000   L  I0.0      Load manual switch
001   A  I0.2      Anded with start button
002   =  M0.0      Store it at marker 0.0
003   L  IA0.0     Load analogue input
004   =  MB4.0     Store it at MB4.0
005   L  KB50      Constant. represents 7 m/s
006   =  MB5.0     Store it at marker byte 5.0
007   L  KB184     Constant represents 18 m/s
008   =  MB6.0     Store it at marker byte 6.0
009   L  KB204     Constant represents 20. m/s
010   =  MB7.0     Store it at marker byte 7.0
011   CP0 I1W:MW4;I2W:MW5  Gt:M0.1-compare IA.0 and 7 m/s (if
                                          greater set M0.1)
012   CP1 I1W:MW4;I2W:MW6  LT:M0.2-compare IA.0 and 18 m/s (if
                                       less than set mo.2)
013    CP2 I1W:MW4;I2W:MW7  Gt:M0.3-compare IA.0 and 20 m/s (if
                                          greater set mo.3)
014   L  I0.1     Load. auto switch
015   =  M0.5     Store it at marker 0.5
016   TR0         set:mo.5 IW:KW10 Eq:mo.6  Set  timer with marker
                                                        0.5
017   L  M0.6     Output from timer
018    A  NI0.4    Anded do not the reset button
019   =  M0.7     and store it at marker 0.7
020   L  M0.7     marker 0.7
021   A  M0.1     and to output of comparator 0
022   =  M2.0     Store it at M2.0
023   L  M0.7     marker 0.7
024   A  M0.2     and to output of comparator 1
025   =  M2.1     Store it at M2.1
026   L  M0.7     marker 0.7
027   A  M0.3     Anded to output of comparator 2
028   =  M2.2     store it at M2.2
029   L  M0.7     Marker 0.7
030   A  M0.4     Anded to output of comparator 3
031   A  NI0.6
032   =  M2.3     store at marker 2.3
033      TR1      S:M2.0  IW:KW1200; EQ: M0.8
034      TR2      S M2.1  IW:KW600; EQ:M0.9
```

```
035       TR3     S M2.2  IW:KW600; EQ:M0.10
036       TR4     S M2.3  IW:KW1200; EQ:M0.11
037    L  I.01     Load auto switch
038    A  M0.8    Anded to output of TR1
039    A  M0.9    Anded to output of TR2
040    =  M0.12   marker 0.12
041    L  M0.0
042    O  M0.12
043    S  M1.14
044    L  M0.10
045    O  M0.11
046    =  M0.15
047    L  M0.15
048    A  I0.1
049    =  M1.0
050    L  NI0.0
051    A  NI0.1
052    =  M3.0
053    L  I.03      Stop button
054    O  M1.0
055    O  M1.12
056       M3.0
057
058    =  M1.1
059    L  M1.1
060    R  M1.14     Reset marker 1.14
061    L  I0.6      Lower bull gear
062    O  I0.7      Or upper bull gear
063    =  M1.2      Store at marker 1.2
064    L  M1.2      Main contactor
065    O  NM2.9     and bull gear Limit switches
066    =  M2.12     store at marker 1.3
067    L  I0.5      S:M1.4;IW:KW2;QW:MW9 main contactor
068    A  M2.12     and bull gear limit switches or low RPM
069    =  M1.3      Store at marker 1.3
070     C  0.0       S:M1.4; IW:KW2; QW:MW9 High speed RPM counter
                    from generator counter Store at MW9
071       TR5      S:M1.4;IW:KW5;EQ:M1.5  timer for 500 m/s
072    L  M1.5     Output from Timer
073       JCN 087  Jump if timer isn't finished
074    L  KW297    Constant represents 1188 RPM
075    =  MW10     Store it at marker word 10
076       CP4      I1W:MW9;I2W:MW10;GT:M2.4  If RPM  greater than
                                              1188 set M2.4
077    L  KW 325   Constant represents 1300 RPM
078    =  MW11     Store at marker word 11
079        CP5      I1W:MW9;I2W:MW11;GT:M1.7  If RPM greater than
                                          1300 set marker 1.7    077
                   L  KW250          Constant Represents 1000 RPM
```

```
080     =  MW13     Constant Represents 1000 RPM  Store at marker
                    Word 13
081        CP3      I1W:MW9; I2W:MW13; Lt. M0.4
082    L   KW 225
083    =   MW12      Constant Represents  900 RPM  Store at marker
word                12
084        CP7      I1W:KW9; I2W:MW12; Lt. M2.8
085    L   KW75     Constant represents 300RPM
086    =   MW14     Store it at marker word 14
087        CP8      I1W:MW9; I2W:MW1.4; Gt:M2.9
088     L  K1
089    R   M1.4     Reset high speed counter and timer
090    JP   65      Jump back to line 65
091    L   K1
092    =   M1.4     Set counter and timer
093    L   NI0.3
094    A   I0.1
095    =   M1.8
096    L   NI0.5
097    A   M1.13
098    =   M1.9
099        TR6      S:M1.9; IW:KW1800; EQ:M1.10
100    L   M1.10
101    O   M1.8
102    O   1.7
103    O   M1.3
104    O   M2.11
105    =   M1.11
106    L   M1.11
107    S   M1.12    Set the trip
108    L   I0.4
109    R   M1.12    Reset the trip
110    A   NM1.12
111    =   Q0.0
112    L   M1.14
113    A   NM1.12
114    =   M1.13
115    L   M2.4     Load marker 2.4
116    S   M1.6     Set marker 1.6; closes main contactor
117    L   M1.12    Load trip output
118    R   M1.6     Reset marker 1.6; opens main contactor
119    L   M1.13    Load trip output
120    =   Q0.1     Reset marker 1.6; opens main contactor
121    L   M1.13
122    =   Q0.2
123    L   M1.12
124    =   Q0.3
125    L   I0.5
126    A   NM1.12
```

```
127    =  Q0.4
128    L  M1.13
129    A  NM1.2
130    A  M2.8
131    =  Q0.5
132       TR8       SNM1.6    IW 100  Eq.M2.7
133    A  AM1.13
134    L  NM2.7
135    =  Q0.6
136        TR7  S:Q0.5; IW:KW200; EQ:M2.10 Timer for Low RPM

137    L  M2.10     Output from timer
138    A  NM2.9
139    =  M2.11
140    L  Q0.8      Low bull gear output
141    O  Q0.9      High bull gear output
142       NOP       For future use (low lube flow)
143       NOP       For future use (vibration)
144    O  Q0.12     RPM Fault
145    O  Q0.13     High speed shaft
146    O  Q0.14     Expired time
147    O  Q0.15     Stop pushed while in auto
148    =  M2.5
149    L  NM2.5
150    A  M1.12
151    =  M2.6
152    L  M2.6
153    A  I0.6

154    S  Q0.8
155    L  M2.6
156    A  I0.7
157    S  Q0.9
158       NOP
159       NOP
160       NOP
161       NOP
162       NOP
163       NOP
164    L  M2.6
165    A  M2.9
166    S  Q0.12
167    L  M2.6
168    A  M1.7
169    S  Q0.13
170    L  M2.6
171    A  M1.10
172    S  Q0.14
173    L  M2.6
```

```
174   A  M1.8
175   S  Q0.15
176   L  I0.4     Reset all output from Q0.8 to Q0.15
177   R  Q0.8
178   R  Q0.9
179      NOP
180      NOP
181   R  Q0.12
182   R  Q0.13
183   R  Q0.14
184   R  Q0.15
```

PS3

Klockner-Moeller has developed a compact, rugged low cost, programmable controller PS 3.

Bearing in mind the variety of functions required of modern control systems, the highly efficient PS 3 has a unit extension facility. Its analog input/output capability makes it ideal for closed loop controls — previously the exclusive domain of larger programmable controllers — and permit its use as a decentralized unit for the PS 32. This, coupled with the comprehensive software library which the microprocessor, offers, makes the PS 3 eminently suitable for machine controls of low to medium complexity.

Its high speed input (10 kHz) and powerful arithmetic function +, −, ×, ÷, embodies the complete solution for high speed counting.

Communication with a hierarchical computer/programmer is an essential requirement of any PC system. Having two RS 485 interface ports, the PS 3 can be programmed via a hand held programmer (PRG 3), a light-pen programmer (using the PRG 300) or with any IBM-PC or compatible unit.

Features

- Real-time clock
  Up to 32 preselectable timed events
  3 decision parameters for testing conditions:
  LT - less than present time
  EQ - at present time
  GT - greater than present time
  Applications: Traffic light controls, energy management systems, and other timed related control.

- Arithmetic functions:
  Four functions:
  ADD - Addition
  SUB - Subtraction
  MUL - Multiply
  DIV - Division
  Negate functions
  Applications: Batch processes requiring some formulations, data handling, etc.

- Analog inputs and outputs
  Quantity -4 inputs per unit (PS 3-AC or PS3-DC)
  0-10V or 4-20mA (using loading resistor)
  Quantity - 1 output per unit (PS3-AC or PS3-DC)
  0-10V/1mA
  Maximum cable length - 10 m screened
  Applications: Control and monitoring of process variables, etc.

- High-speed input (10 kHz)
  Quantity -1 per unit (PS3-AC or PS3-DC) 10 kHz, 24V DC, 10mA. τ_0 ~30 V
  Maximum cable length - 10 m screened.
  Applications: High-speed machinery control

- 32 timers 0.1 to 6553.5 seconds
- 32 counters Up and down
- 32 shift registers Forward and reverse 16 step
- 32 comparators for values from 0 to 65,535
- 576 internal relays (Markers)
- 64 latching relays (Retentive markers)
- 1 one second pulsing marker
- 1 real-time clock (PS 3-AC or PS 3-DC)
- DIN rail mounting
- Connection to heirarchical programmable controller/computer
- Hand-held programmer
- Light-pen programmer
- IBM-PC compatible programming software
- RS 485 noise immune interface.
- Expandable

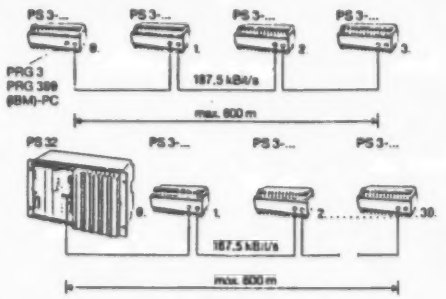
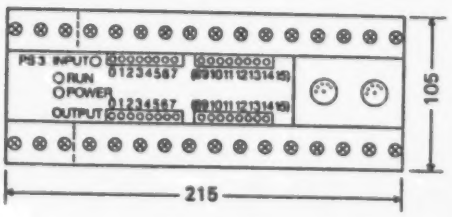


Figure 1

Technical Data

	PS 3-AC	PS 3-8	PS 3-DC
Power supply	110/120 VAC 50-60Hz 220/240 VAC 50-60Hz	110/120 VAC 50-60Hz 220/240 VAC 50-60Hz	24 V DC 24 V DC
Inputs			
Digital + 24V (opto-coupled active H technology)	16	8	16
Analog 0... 10 V DC	4	—	4
High-speed counter input 10 kHz	1	—	1
Outputs			
Transistor + 24V 0.5A	—	—	16
Relay 0... 240 V AC, 2A (24VDC, 0.5A)	8	8	—
Analog 0... 10 V DC	1	—	1
User program memory	1k instructions	1k instructions	1k instructions
Internal relays (markers)	576	576	576
Latching relays (retentive markers)	64	64	64
Program modules			
Timers, counters	32 each	32 each	32 each
Comparators, shift registers	32 each	32 each	32 each
Clock modules	32	—	32
Real-time clock with calendar	1	—	1
Arithmetic functions (+, −, ×, ÷)	yes	yes	yes
Bit, byte, and word markers	yes	yes	yes
Cycle time for 1K addresses	typically < 5 ms	typically < 5 ms	typically < 5 ms
Status indication	LED	LED	LED
Drop-out delay	5 ms	5 ms	5 ms
Isolated contacts	yes	yes	no
Operating temperature	0-55°C	0-55°C	0-55°C
Weight	3 kg	3 kg	2 kg

PS 3 Dimensions



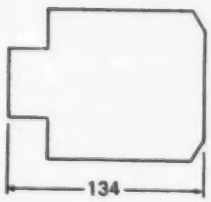


Figure 2

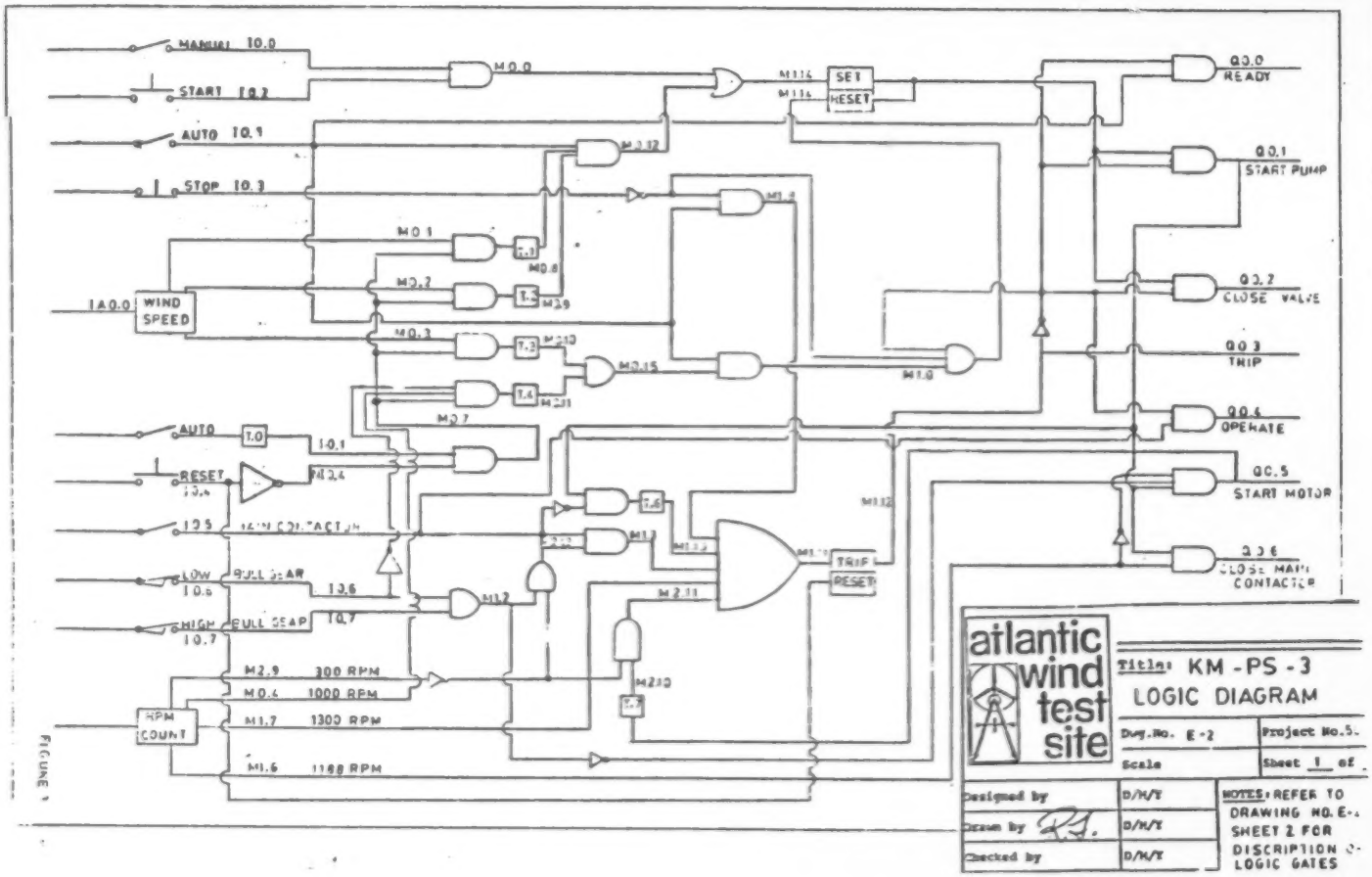

MANUAL I0.0
START I0.2
AUTO I0.1
STOP I0.3
IA0.0 WIND SPEED
AUTO
RESET
I0.5
LOW I0.6
HIGH I0.7
RPM COUNT
M2.9 300 RPM
M0.6 1000 RPM
M1.7 1300 RPM
M1.6 1188 RPM
SET
RESET
TRIP
RESET
Q0.0 READY
Q0.1 START PUMP
Q0.2 CLOSE VALVE
Q0.3 TRIP
Q0.4 OPERATE
Q0.5 START MOTOR
Q0.6 CLOSE MAIN CONTACTOR
atlantic wind test site
Title: KM-PS-3
LOGIC DIAGRAM
Dwg.No. E-2
Project No.5.
Scale
Sheet 1 of
Designed by D/H/T
Drawn by D/H/T
Checked by D/H/T
NOTES: REFER TO DRAWING NO. E-4 SHEET 2 FOR DISCRIPTION OF LOGIC GATES

Figure 3

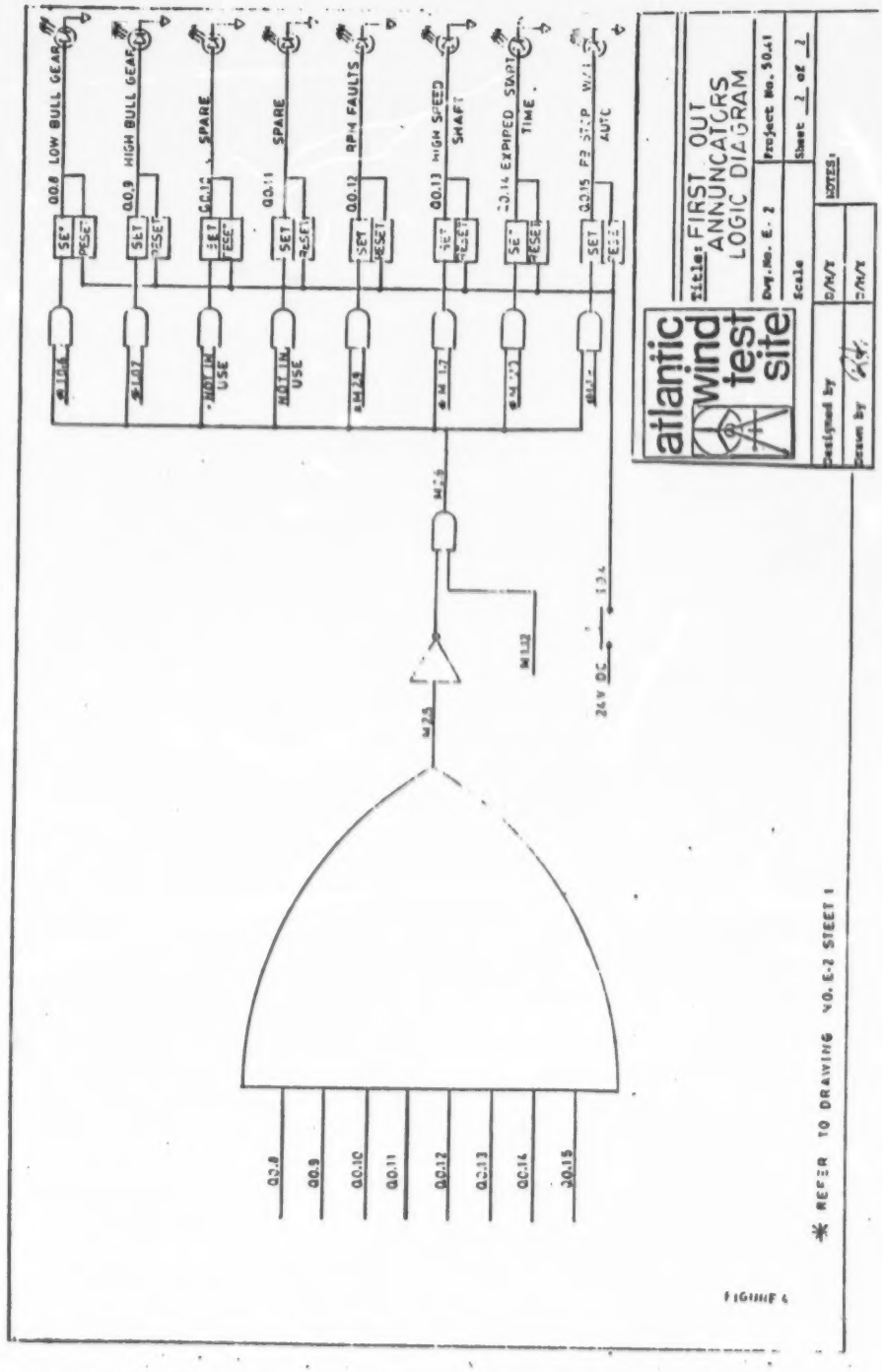

Q0.8 LOW BULL GEAR
Q0.9 HIGH BULL GEAR
SPARE
Q0.11 SPARE
Q0.12 RPM FAULTS
Q0.13 HIGH SPEED SHAFT
Q0.14 EXPIRED START TIME
Q0.15 E2 STOP W/I AUTO
SET
RESET
NOT IN USE
NOT IN USE
M1.3
M1.2
24V DC
Q0.8
Q0.9
Q0.10
Q0.11
Q0.12
Q0.13
Q0.14
Q0.15
* REFER TO DRAWING NO. E-2 SHEET 1
atlantic wind test site
Title: FIRST OUT ANNUNCIATORS LOGIC DIAGRAM
Dwg. No. E. 2
Project No. 50.41
Scale
Sheet 1 of 1
Designed by
D/M/Y
Drawn by
D/M/Y
NOTES:

Figure 4